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RAPID ROAD CONSTRUCTION USING MEMBRANE-ENVELOPED SOIL LAYERS

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Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

February 1973

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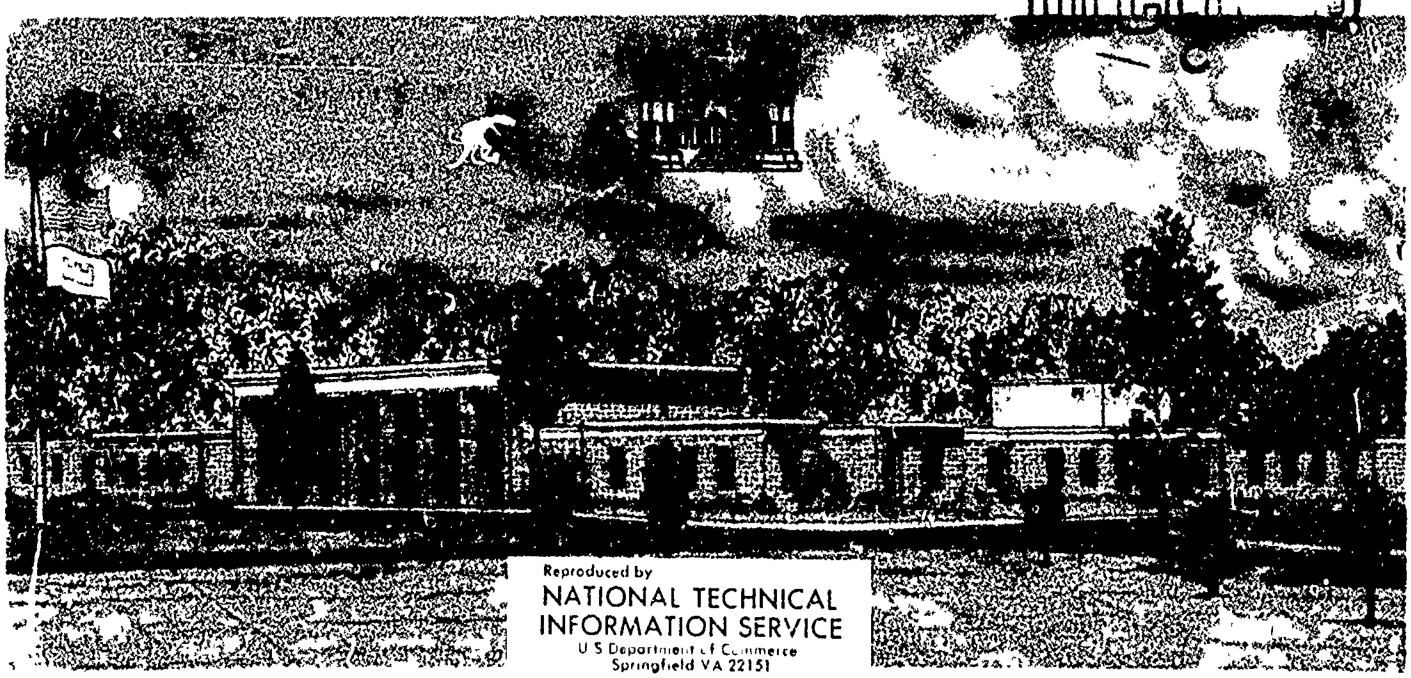
by

A. H. Joseph, R. D. Jackson, S. L. Webster



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13. ABSTRACT Military roads require high-strength foundation layers to support ground vehicles in the theater of operations (TO). In many instances, sizable construction effort and costs are required in obtaining material and producing suitable roads. New road building techniques are needed to reduce the construction time and costs of these roads. The objective of this investigation was to develop construction techniques and procedures for employing a membrane-enveloped soil layer (MESL) as a base course to allow rapid road construction in the TO. Construction techniques for encapsulating in situ or locally available fine-grained soils in waterproof membranes were developed. A test road was built containing both MESL and conventional-type base courses. Traffic tests were conducted, and construction requirements for MESL base courses were determined. A demonstration MESL road was then constructed to test the MESL concept. Also, a test facility for rapidly evaluating membrane materials and other surfacings for military roads was designed and constructed. Various surfacing materials were tested using this new facility. The test facility is a vast improvement over previously used methods for applying traffic. The results of the investigation indicate that a fine-grained soil can be used in MESL base course road construction and can be protected successfully from surface and subsurface water intrusion. Compaction of a full 12-in. MESL of fine-grained soil to 95 percent of CE 12 density (AASHO T-180 Method) is sufficient to support traffic operations of a 5-ton, 6x6 military dump truck loaded to its maximum weight for highway travel. Sheets of 6-mil-thick polyethylene can be used as the lower membrane for the MESL. Of the upper membranes tested, the asphalt polypropylene membrane containing a single layer of product D performed the best. This membrane survived over 55,000 coverages of traffic with no failures. Traffic was applied with a load cart having dual 11:00-20 tires loaded to 9,000 lb at 70-psi tire pressure.

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FOREWORD

The investigation reported herein was sponsored by the Office, Chief of Engineers, U. S. Army, under Military Engineering Design and Expedient Construction Criteria, Project No. 4A062112A859, Task 01, "Expedient Road and Storage Area Design Criteria," Work Unit 001, "Rapid Road Construction." The investigation was conducted during the period of July 1969 to January 1971.

Engineers of the U. S. Army Engineer Waterways Experiment Station (WES) who were actively engaged in the planning, testing, and reporting phases of this investigation were Messrs. A. H. Joseph, R. D. Jackson, and S. L. Webster. The work was performed under the general supervision of Messrs. J. P. Sale and R. G. Ahlvin, Chief and Assistant Chief, respectively, of the Soils and Pavements Laboratory, WES. This report was prepared by Messrs. Joseph, Jackson, and Webster.

COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE, were Directors of WES during the conduct of this investigation and publication of this report. Mr. F. R. Brown was Technical Director.

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CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
mils	0.0254	millimeters
inches	2.54	centimeters
feet	0.3048	meters
yards	0.9144	meters
square yards	0.836127	square meters
ounces	28.3495	grams
pounds	0.45359237	kilograms
tons (2000 lb)	907.185	kilograms
gallons per square yard	4.5273	cubic decimeters per square meter
pounds per square inch	0.6894757	newtons per square centimeter
pounds per cubic foot	16.0185	kilograms per cubic meter
feet per hour	0.3048	meters per hour
miles per hour	1.609344	kilometers per hour
Fahrenheit degrees	5/9	Celsius or Kelvin degrees*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

RAPID ROAD CONSTRUCTION USING MEMBRANE-ENVELOPED SOIL LAYERS

PART I: INTRODUCTION

Background

1. Military roads require high-strength foundation materials on which flexible surfacings can be placed. Materials that are commonly used for this purpose are granular materials from natural deposits, crushed rock, or, in some cases, stabilized in-place soils. In many instances, sizable construction effort and costs are required in obtaining material and producing a foundation layer using conventional techniques.

2. The basic difference in soils from the standpoint of strength is their water-susceptibility characteristics. Some soils are adversely affected by water, in that they lose most of their strength when they become saturated; consequently, such soils have not been used as structural foundation layers for pavements. Instead, the customary procedure has been to select a material that is not adversely affected by water or to treat the soil that is to be used with a chemical additive (stabilizing agent) to increase the resistance of the soil to the detrimental action of water. This conventional type of construction requires that water content and density be closely controlled if satisfactory results are to be expected. Selection of soil type and exercise of precise construction control become less important if the soil can be protected from changes in water content after construction.

3. Experience has shown that compacted fine-grained soil exhibits high strength that can be maintained if the soil is kept dry. If a compacted layer of fine-grained soil could be waterproofed by complete encasement in waterproof membranes, it could be used as a base course for a roadway in the theater of operations (TO). The membrane envelope would have to protect the soil layer from intrusion of rainwater from the top and from groundwater or capillary water in the subgrade. If

the upper waterproof membrane was capable of supporting rubber-tired traffic operations, the technique could be employed. Results of previous investigations[1,2,3] indicate that such a concept for road building is feasible.

Objectives of Investigation

4. The primary objective of this investigation was to develop construction techniques and procedures for employing a membrane-enveloped soil layer (MESL) as a base course to allow rapid road construction in the TO. The primary effort was directed toward the development of earth-handling techniques required to encapsulate soils to be used as foundation layers. Secondary efforts were made to determine the construction requirements for the MESL bases, build a demonstration road to test the concept, evaluate the membrane surfacing materials, and establish MESL surfacing requirements for military roads.

Scope of Report

5. This report describes the investigation in four separate phases as follows:

- a. Phase I: Development of Earth-Handling Techniques. This portion of the study was devoted to developing construction methods for encapsulating soil in a waterproof membrane. This phase of the study was also devoted to earthwork-handling techniques and involved the determination of the most efficient means of utilizing equipment and personnel to construct an MESL roadway.
- b. Phase II: Development of Minimum Construction Requirements. A test road was built containing both MESL and various conventional base courses. Traffic tests were conducted and comparative data were obtained to determine construction requirements for MESL base courses.
- c. Phase III: Demonstration Road Construction and Performance. A test road was constructed using MESL construction techniques to serve as a demonstration road for the MESL concept. It was laid out in the shape of a figure eight to incorporate curves and an intersection. Also, a hillside was included as part of the road. This report

presents information regarding the performance of the MESL road to date.

d. Phase IV: Test Facility for Evaluating Military Road Surfacings. A test facility was designed and constructed for the purpose of rapidly evaluating membrane materials and other surfacings for military roads. The results of tests conducted to date on the various surfacing materials are included herein.

Definition of Terms

6. For clarity, certain terms used in this report are defined as follows:

a. Fine-grained soils. Soils with more than 50 percent of the material by weight passing the No. 200 U. S. standard sieve and which classify as CL, CH, ML, or MH according to the Unified Soil Classification System.[4]

b. Membrane. Waterproof film or layer used for surface and subsurface protection of the soil in an MESL base.

c. MESL base. A base course for roadways constructed of compacted fine-grained soil completely encased in waterproof membrane in order to prevent loss of strength due to intrusion of surface and subsurface moisture. MESL construction is sometimes referred to as mattress construction.

d. MESL road system. A road with an MESL base course constructed from in situ subgrade soil or locally available soil. The upper membrane must be capable of supporting limited operations of rubber-tired traffic.

e. Roads with shoulders. Roads on which construction equipment can operate on the borders outside the confines of the trafficable roadway.

f. Roads without shoulders. Roads on which construction equipment operations are restricted to the confines of the trafficable roadway, such as in narrow cuts and fills and in places where there are obstructions along the roadway.

PART II: DEVELOPMENT OF EARTH-HANDLING TECHNIQUES (PHASE I)

7. A site on the U. S. Army Engineer Waterways Experiment Station (WES) reservation was cleared, and a roadbed was built utilizing the existing lean clay subgrade. This roadbed served as the work area for developing the earth-handling techniques required for construction of an MESL road system.

8. Techniques for constructing three types of roads have to be considered for MESL road systems: (a) roads with shoulders, (b) roads without shoulders, and (c) roads on soft subgrades. For the first two techniques, it was assumed that the in-place roadbed soil would be used in the MESL and that construction would take place in the dry season when the water content of the soil is within proper construction limits. It was assumed that the third technique would be used in areas where the in-place soil is too wet to be encapsulated, such as in low-lying areas with high water tables. Under these conditions, local soil having a suitable water content would be hauled in and used in the MESL.

9. For the purposes of this study, it was assumed that all preliminary grading had been completed and that grades and drainageways had been established. This assumption was made because the construction techniques for these steps are the same for MESL-type road construction as for conventional road construction.

10. The results of the work conducted under this phase of the project are presented in a separate report.[5] The main obstacles encountered in developing the successful techniques for rapid, economical methods for building an MESL road were:

- a. Difficulties in earth removal and replacement for installation of the lower membrane under the roadbed soil to be encapsulated.
- b. Difficulty in rapid installation of the upper membrane without using sophisticated equipment. The primary obstacle was installing the membrane on curves without having wrinkles.

In developing the MESL construction techniques described in reference 5,

several optional techniques were tried or considered. A brief discussion of these follows.

Earth Removal

11. In order to place the lower membrane and to encapsulate the roadbed soil, the soil must first be removed, the lower membrane placed, and the soil replaced. Before developing the satisfactory bulldozer technique for removing this soil (reported in reference 5), other methods were tried or considered.

Grader

12. A road grader was used in an attempt to blade the soil from the road center line to the shoulder area where the soil could be stockpiled in a windrow. Only small quantities of soil could efficiently be rolled laterally using this method. This was true even after the soil had been loosened by a plow. Many passes with the grader were required to move any significant amount of soil; therefore, this method was abandoned since it was too time-consuming.

Scraper

13. The use of a scraper was considered next. A scraper can generally move large quantities of soil in an efficient manner. The plan was to scrape a 100-ft-long* section of roadbed to a desired depth and to discard the displaced soil. Then the lower membrane was to be placed in this section. After this, the next 100-ft-long section was to be scraped to the same depth, and the displaced soil was to be placed on the lower membrane in the previous section. This procedure was to be repeated until the road was completed. A preliminary study indicated that this procedure required use of an expensive high-strength lower membrane to support the traffic operations of the loaded scraper as it placed the soil on the membrane; therefore this method was also abandoned.

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* A table of factors for converting British units of measurement to metric units is presented on page ix.

Earth Replacement

14. After the soil had been removed by the bulldozer technique and the lower membrane had been placed, several techniques were tried for moving the soil that had been stockpiled along the shoulder areas onto the lower membrane.

Grader

15. A grader was used in a first attempt to roll the windrow of soil onto the membrane. The idea was to cover the membrane uniformly with the soil, compact the soil, and then blade the outer 2 ft of soil from the membrane to expose the membrane edge for bonding with the upper membrane. No problems were encountered until the soil was bladed from the membrane edge. It was found that the membrane had shifted in spots and that the grader could not remove enough of the soil from the edge without tearing the membrane.

Grader plus boards

16. A second attempt was made in which the outer 2 ft of membrane was folded four times and placed under 2- by 6-in. by 16-ft boards. The boards anchored and protected the edge of the membrane as the grader rolled the windrow of soil onto the section. Approximately 1 ft of soil was uniformly placed over the boards and membrane. After the section had been covered, the grader, operating from the shoulder, easily removed the soil above the boards with the edge of its blade. Two men then removed the boards and unfolded the 2-ft membrane edge. This technique could work on straight sections of road, but it was somewhat time-consuming and required much hand work.

Bucket loader

17. A technique using a bucket loader with a long side chute was tried. The bucket loader operated from the road shoulder. It picked up the soil from the windrow stockpile, elevated it to the side chute, and dumped it onto the membrane. Forward progress for this operation was only about 100 ft every 35 min. Since this technique was time-consuming and involved a rather uncommon piece of equipment, it was abandoned.

Front-end loader

18. A technique using a front-end loader for earth replacement was then tried and developed. The successful use of this technique required that the front-end loader be capable of removing and installing the windrow of soil without burying the edge of the lower membrane. To facilitate this operation, the windrow of soil should be 2 ft or more away from the membrane edge. This allows the front-end loader room to operate without spilling soil onto the membrane edge. Also, the front-end loader should not spin or slide its wheels when on the lower membrane.

Upper Membrane Placement

19. Polypropylene-asphalt membrane is used as the upper membrane to furnish a waterproof, dustproof wearing surface. It is formed by applying emulsified asphalt to the surface of the soil layer, placing the polypropylene material, applying a second coat of asphalt, and then placing a blotter layer of sand. This will form a wearing surface for light-duty traffic and a foundation for other surfacing materials for heavy-duty, long-life pavements.

20. In developing the upper membrane placement techniques presented in reference 5, several other techniques were tried or considered. A simply constructed membrane-laying yoke attached to an asphalt distributor truck worked well on straight sections of roadway. On curves, however, severe wrinkling occurred as the upper membrane was placed. On slight degree curves, the membrane was cut when wrinkles developed, the laying yoke and distributor truck were realigned, and the laying operation was resumed. On sharper curves, hand placement of the membrane was much faster and more convenient and virtually eliminated wrinkles.

21. A technique using only one application of emulsified asphalt was tried. A curved section of roadway, with the lower membrane and compacted soil installed, was selected. The polypropylene material was unrolled and placed directly on the compacted soil layer and exposed lower membrane edges. Proper joints were formed, and the material was

held in place by nails driven directly into the compacted soil layer. A surface application of 0.45 gal/sq yd of C-RS-2 (ASTM designation) emulsified asphalt was applied over the polypropylene material. A check revealed that the asphalt penetration was insufficient for bonding the material to the soil layer, to the underlap of polypropylene material at the joints, or to the lower membrane edges. After a few local rains, sufficient water had penetrated the upper membrane to cause the compacted soil layer to become soft.

22. If a technique were developed using only one application of asphalt applied after the polypropylene material was installed, certain benefits might result. The polypropylene material could be placed and all joints sewn together by field sewing machines. The asphalt could then be applied. Stronger joints might result between sections of polypropylene material used in the upper membrane. This would be beneficial, especially on curves where some joints have a tendency to slip under traffic.

23. The use of a stiff-bristled broom was found to be helpful during upper membrane placement. After application of the initial layer of asphalt and placement of the polypropylene material, small wrinkles that developed were easily removed by sweeping with such a broom. Sweeping with the broom also helped to ensure good ground contact with the membrane. Joints of sections of polypropylene material seemed to bond better when swept with a broom. Brooming is not required for most membrane placement; however, field judgment can be used for determining the need for brooming.

PART III: DEVELOPMENT OF MINIMUM CONSTRUCTION REQUIREMENTS (PHASE II)

Construction of Test Road

24. A test road was constructed utilizing the techniques developed in Phase I for the MESL bases, and, for comparison, several conventional-type bases were included in the test road. The test road consisted of eleven 50-ft-long test items as shown in plate 1 and was 24 ft wide to permit two traffic lanes. Test items 1-4 were intended to represent conventional base construction techniques and were included in the test road for comparison with the MESL bases. Items 1 and 2 consisted of 2 and 4 in., respectively, of hot-mix asphaltic concrete placed directly on the undisturbed subgrade. Item 3 consisted of 12 in. of well-compacted clay gravel over the undisturbed subgrade. Items 4 and 5 were lean clay subgrade material stabilized with 6 percent lime and cement, respectively.

25. Test items 6-11 were MESL bases, each containing 12 in. of encapsulated lean clay soil and utilizing 6-mil-thick polyethylene as the lower membrane. Different soil conditions were created in each of the test items in an attempt to define the minimum amount of construction effort necessary to provide a satisfactory road base. The water content and compaction conditions of items 6-11 are noted in plate 1. In items 6, 8, and 10, compaction consisted of applying 10 coverages of a 40,000-lb four-wheel roller. The soil used in items 7, 9, and 11 was not compacted. Also, to obtain preliminary information on the performance of polypropylene membranes, different types of upper membranes were incorporated. For upper membranes having one layer of polypropylene material, 0.4 gal/sq yd of C-RS-2 emulsified asphalt was applied followed by the polypropylene and finally, another application of asphalt at a rate of 0.25 gal/sq yd. If two layers of polypropylene material were used, the second layer was applied at this point, followed by a final application of 0.25 gal/sq yd of asphalt. Surfaces were then blotted by a light application of sand. It was not intended that the

upper membranes be a test variable since they were to be evaluated in Phase IV. One lane of the test road was trafficked in a dry condition and contained one layer of polypropylene material in the upper membrane. The other lane, which contained two layers of polypropylene material in the upper membrane, was subjected to wet-shoulder conditions during traffic. Test items that survived the wet-shoulder traffic were subsequently flooded, and additional traffic was applied. Photo 1 shows the completed test road prior to trafficking.

Traffic Tests and Results

Test vehicle

26. Traffic was applied by a military 5-ton, 6x6 dump truck having a gross weight of 42,000 lb and a tire inflation pressure of 70 psi (fig. 1). This vehicle has an average equivalent single-wheel

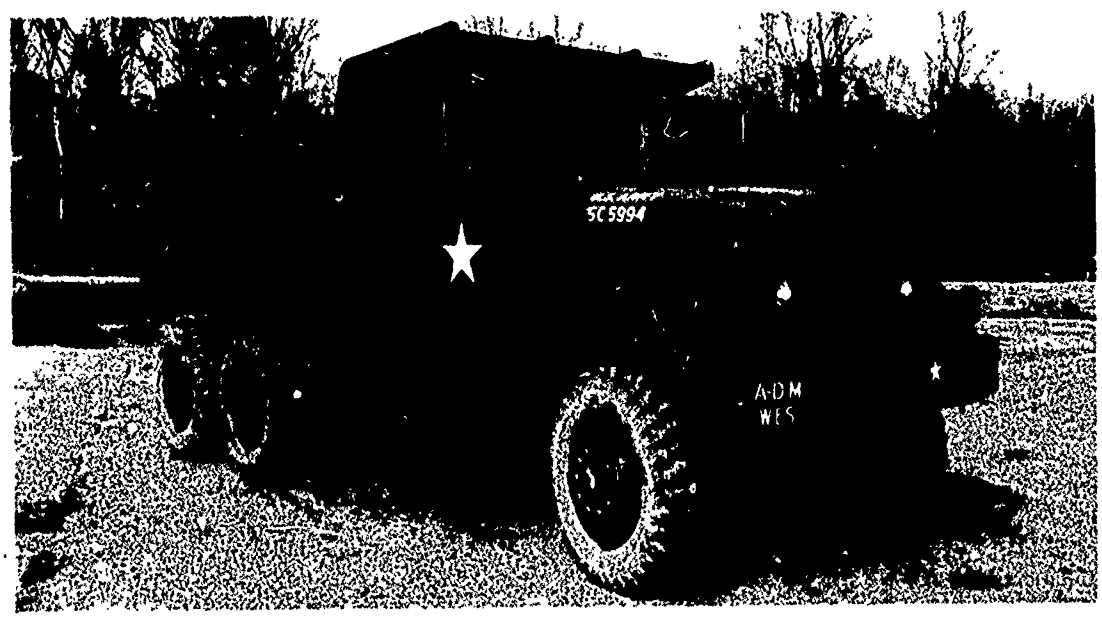

Fig. 1. Traffic test vehicle

load (ESWL) of approximately 5000 lb. Since each of the three axles provided one coverage of this ESWL, it was concluded that one pass of the vehicle resulted in three coverages of a 5000-lb ESWL. Therefore,

all traffic data referred to herein will be in terms of coverages with a 5000-lb ESWL.

Dry-lane traffic tests

27. Traffic was applied to all items by driving back and forth over the entire length of the test road. A rope center line was employed so that representative, channelized traffic was obtained. After 900 coverages, items 1 and 11, which are shown in photos 2 and 3, respectively, were considered failed. A close-up of the sheared membrane in item 11 is shown in photo 4. Traffic was continued to a total of 3000 coverages on items 2-10. Typical cross sections of items 2-10 prior to traffic and after 3000 coverages are shown in plate 2. The performances of these items are discussed in the following paragraphs.

28. Item 2. This item is shown in photo 5 after 3000 coverages. As can be seen, localized failures occurred in each wheel path; however, these failures were due to weak spots in the subgrade that had been detected during construction. The overall condition of item 2 at the conclusion of traffic was good.

29. Item 3. This item is shown in photo 6 after 1275 coverages. A severe localized failure occurred in one wheel path due to a wet, weak subgrade condition. A close-up of this failure is shown in photo 7. This failure was repaired after 1275 coverages because it interfered with application of traffic on the other test items. Additional traffic (1725 coverages) was then applied to item 3, making a total of 3000 coverages on item 3. The cross-section data for this item were influenced somewhat by the repair work, but the overall condition of the item was good.

30. Items 4-9. Photos 8-13 show items 4-9, respectively, after 3000 coverages. These items all withstood 3000 coverages without apparent damage. However, the cross-section data indicate that some slight soil deformation did occur in items 7 and 9.

31. Item 10. Photo 14 shows item 10 after 3000 coverages. Significant rutting occurred in this item, as can be seen in the cross section in plate 2. Although the item withstood the full 3000 coverages of traffic, it was in poor condition, and failure was imminent.

Wet-shoulder traffic tests

32. In order to evaluate the performances of the test items for wet weather, water was applied to the shoulder and ditch along all eleven test items for one week prior to traffic. During the traffic tests, the shoulder was flooded. Photos 15 and 16 show the flooded shoulder and the test items during traffic tests. The performances of these test items are discussed in the following paragraphs.

33. Item 1. This item performed in the same manner as it did during the dry-lane traffic tests. The item was considered failed after 900 coverages.

34. Items 2-9. Photos 17-24 show items 2-9, respectively, after 3000 coverages. A localized failure occurred in the outside wheel path at the junction between items 2 and 3. This failure was repaired after 1500 coverages because it interfered with traffic on the test road. Another localized failure occurred in the outside wheel path at the transition between items 7 and 8. However, this failure did not interfere with traffic and was not repaired until 3000 coverages had been completed and photographs taken. Except for the two localized transition failures, items 2-9 withstood 3000 coverages without apparent damage. Cross-section data for these items are shown in plate 3.

35. Item 10. Photo 25 shows item 10 after 3000 coverages. Some rutting did occur in this item, as can be seen in the cross-section data in plate 3. The item was in poor condition, but it could have sustained additional traffic.

36. Item 11. Item 11 performed in about the same manner as it did during the dry-lane traffic tests. Although the surface membrane did not tear, the item was considered failed after 900 coverages due to severe rutting conditions.

Flooded-lane traffic tests

37. Due to the satisfactory performance of most test items during the wet-shoulder traffic tests, it was decided to simulate flooded conditions over the entire traffic lane in items 2-10. These items were submerged under water for 36 hr and then drained. Traffic was then resumed, and the results of this additional traffic are

discussed in the following paragraphs.

38. Item 2. Photo 26 shows item 2 after 1200 coverages. A localized failure occurred in this item. This failure occurred because the trafficking vehicle was operating close to the edge of the item where a weak spot in the subgrade had developed. The remainder of the item withstood the traffic without apparent damage.

39. Items 3 and 4. Photos 27 and 28 show item 3 after 36 coverages and item 4 after 348 coverages, respectively. Complete failure had occurred in the outside wheel path of item 3 after only 36 coverages. Item 4 withstood 348 coverages before sustaining the same type failure.

40. Item 5. Photo 29 shows item 5 after 1200 coverages. The item sustained no apparent damage.

41. Item 6. This item is shown in photo 30 after 1200 coverages. A localized minor rut appeared in the outside wheel path after approximately 30 coverages. The rut seemed to stabilize itself and did not worsen as traffic was continued. After 1200 coverages, the item was considered to have suffered negligible damage and was in good condition.

42. Item 7. Photo 31 shows item 7 after 480 coverages. Complete failure occurred along the outside wheel path.

43. Item 8. Photo 32 shows item 8 after 1200 coverages, which the item withstood without apparent damage.

44. Item 9. This item is shown in photo 33 after 450 coverages. Failure occurred along the outside wheel path over about one-half of the length of the item.

45. Item 10. Photo 34 shows item 10 after 288 coverages. Complete failure resulted along the outside wheel path, and noticeable rutting was apparent along the inside wheel path.

Summary and Analyses of Test Results

Summary

46. Test road data and test results are given in table 1. Plate 4 shows a compaction curve for the subgrade and encapsulated soil, which was a local lean clay having a liquid limit of 40.5 and a plasticity

index of 19.3. Plate 5 presents a CBR design curve for a 5000-lb ESWL with a 70-psi tire inflation pressure.

Analysis of dry-lane test results

47. As can be seen in table 1, the subgrade CBR was approximately 6 under all test items. The curve in plate 5 indicates that this subgrade should have been capable of withstanding about 900 coverages of the 5000-lb ESWL. This agrees very closely with the failure of item 1 at 900 coverages. Item 11 also failed at 900 coverages, but the failure occurred in the encapsulated layer rather than in the subgrade. Low densities were measured in item 11 due to the low moisture content and to the fact that this item received no compaction. Consequently, traffic rutted the item by consolidation and displacement, resulting in surface membrane failure. As noted earlier, item 10 was in very poor condition after 3000 coverages, and significant rutting had occurred for the same reason that it occurred in item 11. However, the compaction applied to item 10 at the time of construction apparently was sufficient to prevent the item from failing during the 3000 coverages. Items 2-9 satisfactorily withstood the full 3000 coverages with only local failures, as discussed earlier.

Analysis of wet-shoulder test results

48. As can be seen in table 1, items 1, 10, and 11 performed in the same manner as they did in the dry-lane traffic tests. Both items 1 and 11 were considered failed at 900 coverages. Item 10 showed significant rutting after 3000 coverages and was in poor condition. All other items satisfactorily withstood the full 3000 coverages with only localized failures at the junctions of items 2 and 3 and 7 and 8, as discussed earlier. From table 1, it can be seen that the densities of items 6 and 8 increased only slightly due to traffic, i.e. 2 and 3 pcf, respectively. Items 7 and 9 showed greater increases in density due to traffic, i.e. 6 and 5 pcf, respectively. Item 10 showed an increase in density of only 1 pcf, indicating that the rutting that occurred in this item was mainly due to soil displacement under traffic. The cross-section data for item 10, shown in plate 3, confirm this observation.

Analysis of flooded-lane test results

49. The performances of items 2-10 under flooded conditions are also presented in table 1. It was under flooded conditions that the water-susceptibility characteristics of each item became apparent. Of the conventional-type bases (items 2-5), only items 2 and 5 withstood the 1200 additional coverages. Items 3 and 4 suffered early failures. Since only a surface membrane was used on these items, water was able to penetrate between the base course and surface membrane along the outer wheel path. Traffic over this wet area caused rutting and rupture of the membrane. Of the MESL bases (items 6-11), only items 6 and 8 withstood the full 1200 coverages. The soil strengths of these two compacted items were sufficient to prevent any significant amount of rutting. Rutting resulted in the other items due to insufficient soil strengths. As the rutting progressed, rupture of the membrane occurred allowing water to enter the MESL.

Conclusions

50. Based on the test results summarized and analyzed above, the following conclusions are believed warranted:

- a. A fine-grained soil can be used in MESL base course road construction and can successfully be protected from surface and subsurface water intrusion, provided proper water content and density control is maintained during construction. This can be accomplished in the field by using the construction techniques developed in Phase I of this project.
- b. The 6-mil-thick polyethylene sheets used in the test reported herein provided a successful lower membrane for the MESL base; however, some caution must be exercised during construction, since this thin membrane can be easily torn by heavy construction equipment.
- c. The asphalt-polypropylene upper membranes used on the test road appear to have performed well; however, these membranes were not intended to be a test variable in Phase II, and will be evaluated in Phase IV.
- d. Compaction of a full 12-in. MESL of fine-grained soil to

95 percent of CE 12 density (MIL-STD-621A, Method 100* CE 12) is sufficient to support traffic operations of a 5-ton, 6x6 military dump truck loaded to its maximum weight for highway travel. Water content of the soil should be at or below optimum during construction; preferably, it should be slightly below optimum.

e. Of the MESL bases tested, items 6 and 8 were comparable in performance to the best conventional bases tested, items 2 and 5.

* Also AASHO T-180 Method B.

PART IV: DEMONSTRATION ROAD CONSTRUCTION AND PERFORMANCE (PHASE III)

Location

51. The demonstration road was located on the WES reservation in a low-lying area containing the lean clay soil described in paragraph 46 and plate 4. A portion of the road incorporated slopes and curves on a hillside consisting of the same type of soil.

Layout

52. A layout of the demonstration road is shown in plate 6. The road was laid out in the shape of a figure eight to incorporate curves and an intersection. Also, a hillside was included as part of the road. The curved portion of the west loop was superelevated as illustrated by section A-A of plate 6. The rest of the road was crowned as illustrated by section B-B. The road was 1600 ft long and was 20 ft wide where superelevated and 22 ft wide where crowned. The center-line profile of the road was generally flat except for the 300-ft-long hillside section, which contained grades up to a maximum of 14.8 percent. The thickness of the MESL base varied with the subgrade conditions encountered during construction. Because of existing subgrade conditions, fill was required to provide a stable platform for construction of the MESL. The center-line thickness taken from the profile data varied from 1.2 to 3.0 ft.

Construction of Demonstration Road

53. The demonstration road was constructed between 11 May and 10 June 1970. The shoulder treatments were applied in early July. The slowest process in building the MESL was earth installation on the lower membrane. This process was accomplished at a rate of approximately 100 ft per hr using three dump trucks to haul the soil an average distance of 300 yd. Upper membrane placement was the second slowest

process. Using the hand-placement technique, 8 hr were required for installing the upper membrane around the 1600-ft-long road.

54. A 50-ft-wide area along the figure-eight center line was cleared of grass and debris down to the lean clay subgrade. Soil water content measurements were obtained at random intervals around the figure eight. The average water content was 22 percent in the top 12 in. of subgrade soil and increased with depth to an average of 27 percent at 22 in. Optimum water content for the CE 12 compaction effort, shown in plate ., is 18.2 percent. An attempt was made to dry the top 12 in. of soil to below 18 percent water content so this soil could be used as the MESL base. The construction techniques developed for roads with shoulders[5] could then be used for building the road; however, the attempt failed. Free water was observed only 2-1/2 ft below the surface in some locations. During attempts to dry the soil using construction equipment, pumping developed and spongy soil conditions resulted. Under the loads imposed by construction equipment, subsurface water rose into the surface layers of the soil.

55. Since the subgrade soil was too wet to be used in the MESL, a similar soil with a suitable water content was located in a nearby hillside. Using this soil, construction techniques developed for roads on soft subgrades[5] were required for building the MESL.

Shoulder material placement

56. Soil for the shoulders was hauled from the nearby hill. A grader was used to shape the shoulders into mounds on each side of the roadway. These mounds served to contain the soil used in the MESL and were spaced to establish the desired road width. The inside faces of the shoulders were made as vertical as possible and were 1 to 1-1/2 ft high.

Lower membrane placement

57. The lower membrane was placed as shown in photo 35. Rolls of 6-mil-thick polyethylene, each containing 100- by 32-ft sections, were unrolled, unfolded, and placed flat on the subgrade surface. Each section of membrane was sufficiently wide to overlay each shoulder approximately 3 ft (see upper portion of photo 35). Section ends of lower membrane were overlapped a minimum of 5 ft to ensure watertightness.

Earth installation

58. Earth installation was accomplished by the back-dump procedure, as shown in photo 36. Dump trucks loaded with suitable soil from the nearby hill back-dumped the soil onto the lower membrane. Then a small bulldozer was used to spread the soil on the lower membrane (photo 37). The initial lift of soil was placed thick enough to support the operations of the bulldozer and loaded dump trucks. Due to the variations in the subgrade strength at the time of construction, the thickness of the initial lift of soil varied. Some locations received only about 8 in. of soil, while others required 24 in. in order to bridge the weak subgrade. Compaction of the initial soil lift was obtained by having the loaded dump trucks drive over different paths as they delivered the soil.

59. A final lift of soil was installed. The thickness of the final lift was sufficient for constructing superelevated curves in the west loop and crowned surfaces in the east loop. The surfaces of each loop were shaped with a grader and compacted to the desired density by a rubber-tired compactor. As the grader shaped the surface of the soil layer, its blade was kept approximately 6 in. away from the exposed lower membrane edge in order to prevent tearing the membrane. Loose soil near the membrane edge was removed by hand shoveling.

Upper membrane placement

60. Before the upper membrane was installed, a grader was used to cut an anchor ditch along the road edges. The lower membrane edges were folded back upon the compacted soil layer, and the grader cut a 1-ft-deep ditch approximately 6 in. from the membrane. The lower membrane was then folded back into the ditch, as shown in photo 38, completing the preparation for upper membrane placement.

61. The upper membrane was installed following the techniques developed in Phase I for placing upper membranes around curves. It was formed using the following materials.

a. Asphalt. The asphalt used was C-RS-2 (ASTM designation), a rapid-setting cationic emulsion.

b. Polypropylene material. Several polypropylene materials,

both woven and nonwoven, were available from various firms. Limited test results on these materials are included in Phase IV of this report. For the demonstration road, a nonwoven polypropylene material, product D, was used. Rolls of polypropylene material, 15.5 ft wide and approximately 350 ft long and weighing approximately 200 lb, were supplied at a cost of $0.45 per sq yd.

62. The surface of the soil layer was sprinkled lightly with water prior to the application of asphalt. Since most of the road surface was curved, all of the upper membrane was hand placed. An initial application of 0.5 gal/sq yd of asphalt was sprayed in sections 16 ft wide and 20 to 50 ft long. The asphalt was sprayed for a sufficient distance over the road edge to completely coat the exposed lower membrane edge. Three men cut sections of polypropylene material to match the length of the asphalt-sprayed surface. Four other men, each holding one corner, placed the polypropylene material over the sprayed area. Placement was such that it bonded with the asphalt-coated lower membrane along the road edge.

63. For each new section of membrane placed, the distributor truck started spraying while over the membrane already installed. A sufficient portion of the installed section of membrane was coated with asphalt to allow a minimum 1-ft lap joint. As each new section of membrane was installed, an overlapping asphalt-sealed joint was formed with the membrane already installed. Photos 39 and 40 show the upper membrane being installed on the first and second halves of the road, respectively. The joints were constructed with the overlapping run on the uphill side for better drainage and waterproofing. The asphalt-sealed joints were swept with a broom to ensure good contact.

64. After the upper membrane had been installed, a final coat of asphalt was sprayed over the MESL surface at a rate of 0.3 gal/sq yd. Photo 41 shows the distributor truck spraying the membrane surface. A light blotter application of fine sand was applied following the final asphalt spray (photo 42).

Shoulder completion

65. After upper membrane installation, a grader and rubber-tired compactor were used to complete the shoulders. The grader, using the

soil obtained when cutting the membrane anchor ditches, backfilled the ditches, thus burying the asphalt-bonded lower and upper membrane edges. Additional soil from the shoulder was bladed upon the outside edge of the superelevated portion of the MESL as illustrated in section A-A of plate 6. Caution was used when blading the soil near the membrane, since the blade of the grader would easily tear the membrane if any contact were made. The shoulders were then compacted using a rubber-tired compactor.

66. The compacted shoulders were treated for erosion control. The types and locations of the treatments applied are shown in plate 7. Basically, three types of treatments were applied.

a. Emulsified asphalt treatment. The outside shoulder from sta 4+20 to 5+50 was sprayed with C-RS-2 emulsified asphalt at a rate of 0.6 gal/sq yd. The asphalt was sprayed directly onto the compacted soil over a 6-ft-wide area extending from the MESL surface.

b. Polypropylene plus surface asphalt treatment. Both shoulders of the west loop, sta 0+00 to 3+70 and sta 12+25 to 16+00, received this treatment. A tack coat of asphalt was sprayed on the outer 1 ft of the MESL surface. Sections of polypropylene 6 to 8 ft wide by 15.5 ft long were placed over the tack coat and shoulder area. The polypropylene surface was then sprayed with just enough asphalt to coat the polypropylene.

c. Asphalt-polypropylene-asphalt treatment. The remaining shoulders, including the intersection corners, received this treatment. Asphalt was sprayed on the shoulder and outer 1 ft of the MESL surface at a rate of approximately 0.3 gal/sq yd. Sections of polypropylene 8 ft wide by 15.5 ft long were placed over the sprayed areas. The polypropylene surface was then sprayed with asphalt at a rate of approximately 0.2 gal/sq yd.

Soil Tests

67. Upon completion of the demonstration road, surface soil tests were conducted. The west loop of the road had an average surface CBR of 21, dry density of 95.4 pcf, and water content of 13.4 percent. The east loop had an average surface CBR of 15, dry density of 98.4 pcf, and water content of 16.8 percent. Drier soil was used in the

west loop due to the softer subgrade conditions that existed in the location of this loop during construction.

Traffic Tests (July-October 1970)

68. The demonstration road prior to traffic tests is shown in photo 43. The white area in the upper right hand corner of the photograph was the source of supply for the soil used in the MESL.

69. Traffic was applied to the road using the vehicle described in paragraph 26. The vehicle was driven from sta 0+00 to 16+00 in a continuous manner. Initial traffic was placed to cover the total road surface to ensure good contact between the upper membrane and soil surface. Then, from 20-31 July, 200 passes were applied. For the first 100 passes, the test vehicle was traveling at approximately 21 mph. All additional traffic was slowed to an average speed of approximately 15 mph. The road was trafficked as a one-lane road, allowing driver freedom for wheel-path positions. Several different drivers were used in applying the traffic to obtain a random coverage pattern. Traffic was reported in terms of passes since the coverage pattern was random.

70. Fifty additional passes were applied in August and 25 more in October, making a total of 275 passes. Photo 44 shows the vehicle traveling along the flat portion of the road, and photo 45 shows the vehicle climbing the 14.8 percent grade on the hill.

71. Approximately thirty 90-degree turns were made at the south corner of the intersection. At the conclusion of each session of traffic, the vehicle turned this corner to facilitate its approach to the off ramp.

Weather Conditions (June-December 1970)

72. Ambient temperatures measured near the road ranged from a high of approximately 105 F in July to approximately 25 F in December. Precipitation on the road was as follows:

Month	Rainfall in.	Accumulative Rainfall, in.
June	5.80	5.80
July	4.58	10.38
August	2.98	13.36
September	2.58	15.94
October	12.09	28.03
November	2.33	30.36
December	3.00	33.36

73. Of the 12.09 in. of rainfall during October, 7.37 in. fell over a two-day period. This caused complete flooding of the low-lying area where part of the road was located. The road, except for the hill portion, was almost completely submerged for several hours during the peak runoff period. A drainage pipe in the east loop was stopped up, and the loop remained full of water for two days. Photos 46-49 show the road during flood conditions. The photographs were taken after the water level had receded approximately 1 ft.

Performance of Demonstration Road

Performance under traffic

74. As noted earlier, the first 100 passes of traffic were applied with the test vehicle traveling at an average speed of approximately 21 mph. This traffic was applied in July when the ambient temperature ranged from 90 to 105 F. Wrinkles in the upper membrane began to develop along the inside road edge in the west loop. Also, some minor shifting of membrane sections in the crowned east loop began to take place. Traffic was slowed to 15 mph, and further wrinkling development and membrane shifting became unnoticeable.

75. At the conclusion of traffic in October, a total of 275 passes of traffic and approximately thirty 90-degree turns on the south corner of the intersection had been completed. The overall condition of the road was as follows:

- a. The west loop suffered only minor membrane wrinkling along the inside road edge. These wrinkles were generally confined to the extreme edge just outside the vehicle wheel paths. The upper membrane maintained a good

bond with the soil layer. Individual membrane sections did not shift under traffic. The MESL was strong enough to prevent any rutting under the traffic loads applied.

b. Upper membrane wrinkling in the east loop was minor and was generally confined to the hill and to the outside half of the road. This minor wrinkling resulted from membrane sections on the outer half of the road shifting under traffic. The center-line joint between inner and outer sections of membrane showed that the outer membrane sections shifted outward a maximum of 4 in. in some locations. However, the performance of the upper membrane and the water resistance of the joints were not affected by the shifting, and the condition of the membrane and soil layer remained good throughout the application of traffic. The MESL was strong enough to sustain the traffic loads applied.

c. Generally, the intersection was in only fair condition at the conclusion of traffic tests. The few turns that were made at the south corner of the intersection were slow-speed turns (less than 10 mph) and caused no apparent damage. However, the cross-type pattern of the regular traffic was beginning to break the bond between the upper membrane and soil surface. At the conclusion of traffic, wrinkles were beginning to develop at the intersection. The cross-type traffic was causing abrasion on the upper membrane, and some small pieces of asphalt were beginning to separate from the polypropylene material.

Effects of weather on performance

76. Normal MESL construction procedures should allow for continuous drainage to an elevation below that of the lower membrane. However, the unusually heavy rainfall that occurred during October submerged most of the demonstration road. The flooding severely tested the waterproofness of the MESL road. The only failure observed occurred along the inside edge of the MESL between sta 15+50 and 0+50. Water entered the MESL at this location and caused the soil layer to become soft over a 6- by 100-ft area along the MESL edge.

77. Ultraviolet sunlight radiation can destroy unprotected polypropylene within a few weeks. However, the thin coat of asphalt sprayed onto the polypropylene surface prevented damage due to ultraviolet radiation.

78. During hot weather, the asphalt within the upper membrane became softer, and the upper membrane became more flexible. The

membrane was apparently more susceptible to shifting and wrinkling under these conditions; this was especially noticeable when traffic was applied at higher speeds. Colder weather did not appear to hamper the performance of the road.

Performance of shoulder treatments

79. The treated shoulders were not traffic-tested. However, their effectiveness for erosion control was evaluated. Of the three types of shoulder treatments applied (paragraph 66), only the asphalt-polypropylene-asphalt treatment was considered effective. The compacted shoulders having this type treatment remained firm and relatively dry. Both the woven and nonwoven polypropylene materials performed well. The compacted shoulders having the other types of treatment were saturated or suffered erosion damage during the heavy October rains.

80. The inside shoulder treatment from sta 2+00 to 3+80 was almost totally destroyed by ultraviolet radiation. Shortly after construction, rain washed some of the newly sprayed asphalt from the polypropylene surface at this location.

PART V: TEST FACILITY FOR EVALUATING MILITARY ROAD SURFACINGS (PHASE IV)

81. This phase of the project was a two-part study. One part consisted of the design and construction of a test track for the rapid evaluation of the material components of MESL construction. The other part was a performance test on polypropylene-asphalt membranes used in MESL construction.

Design and Construction of Test Facility

82. The test facility was designed and constructed by WES personnel. Basically, the facility consists of a 21-ft-wide circular test track that is bounded on its outer edge by a 7-ft-wide portland cement concrete pavement and by a 3-ft-wide pavement on the inner edge. A layout of the test facility is shown in fig. 2. The outer paved area is used for the propulsion unit, and the inner 3-ft-wide paved area is used for an idler bogie. The propulsion unit is anchored to a center pedestal by means of a structural frame that pulls a load cart that can be moved transversely (back and forth) across the test track as the unit travels in a circle. The load cart is designed to carry from 7,000 to 50,000 lb. The maximum speed is approximately 30-40 mph at the light load and approximately 15-20 mph at the maximum load. The test facility is operated from a remote station, from which both the speed of the load cart around the track and the transverse speed can be controlled.

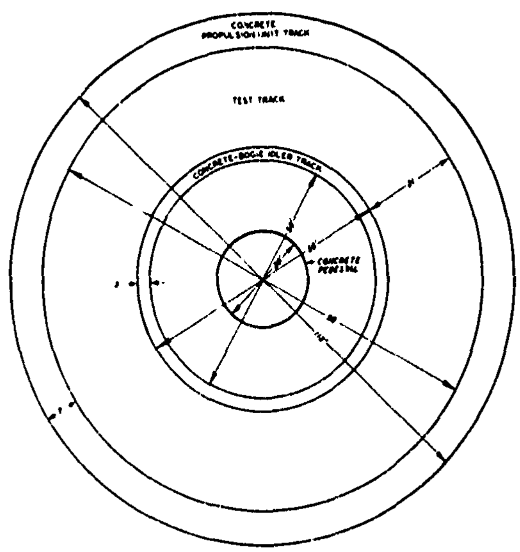

Fig. 2. Test facility

83. The propulsion unit is a 200-hp diesel engine with an

automatic transmission and four-wheel drive. The driving mechanism is mounted on the rear axles of a 2-1/2-ton military truck. The transverse drive mechanism is composed of a 10-hp d-c electric motor, a gear reducing box, and a drum and cable assembly for moving the load cart back and forth. Limit switches are used for reversing the direction of the load cart. These switches can be spaced so that the transverse width can be adjusted from no movement to about 10 ft of movement.

84. The rate at which traffic can be applied is proportional to the load on the cart; however, approximately 10,000 revolutions of the test cart can be made in a 24-hr period with a load of 10,000 lb or less. The speed would be decreased by about 50 percent if the load were increased to 50,000 lb.

Evaluation Tests

Test items

85. Before testing was begun, the subgrade, which was the natural soil of the area, was stabilized with 10 percent portland cement to a depth of 8 in. so that subgrade performance would not be a test variable.

86. Ten test items of equal length were placed on the stabilized subgrade. Five different membranes (products A-E; see key) were used; each membrane was placed in both single and double layers. Products A, B, and C were woven, and products D and E were nonwoven. Characteristics of the membranes are given in table 2.

87. Single layers of products A-E were placed in items 1-5, respectively, and double layers of products A-E were placed in items 6-10, respectively. A layout of the test items is shown in plate 8.

88. The single-layer test items were formed by spraying emulsified asphalt (C-RS-2) on the stabilized soil layer at a rate of 0.3 gal/sq yd, applying a layer of polypropylene material, applying another layer of liquid asphalt at a rate of 0.25 gal/sq yd, and then blotting the surface with fine sand.

89. The double-layer test items were formed in the same manner as the single-layer items, except that instead of sand, a second layer of

membrane was applied after the second application of asphalt. The second layer of membrane was sprayed with emulsified asphalt at a rate of 0.2 gal/sq yd and then blotted with fine sand.

Traffic testing and results

90. Traffic was applied with the load cart shown in fig. 3.

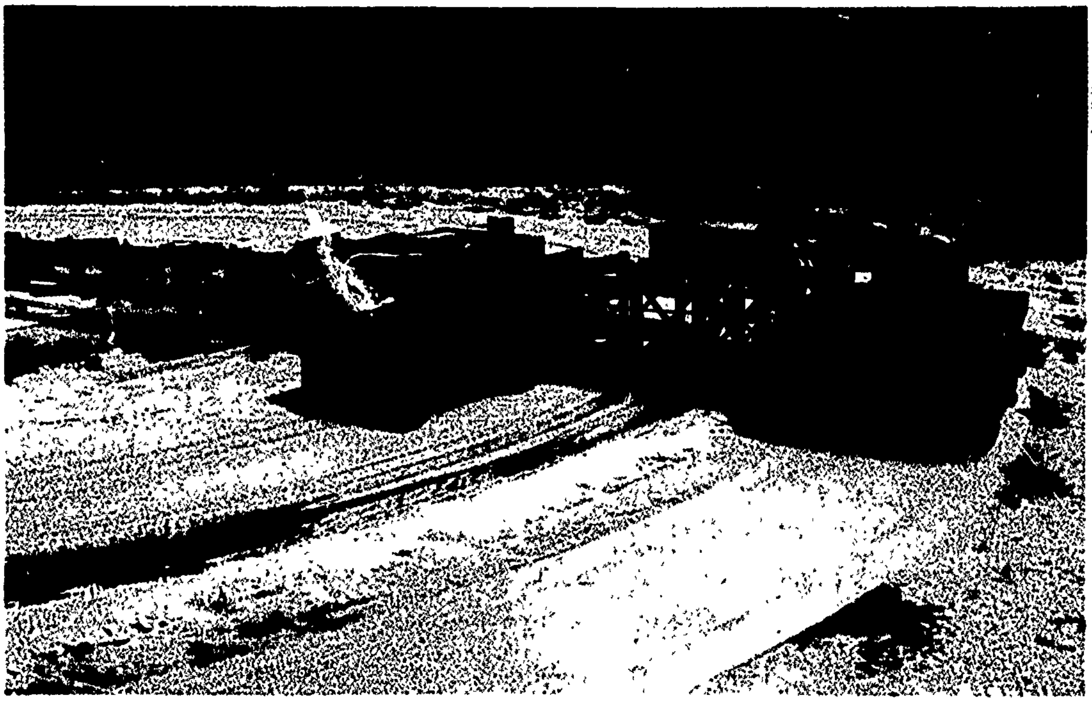

Fig. 3. Load cart and test facility

Total load on the single-axle, dual 11:00-20 tires was 9200 lb (slightly more than the maximum highway load for 5-ton military trucks). Tire pressure was 70 psi.

91. Traffic was applied to successively smaller widths of the traffic lane. Initially, traffic was applied to a 92.50-in.-wide area (equal to 10 tire-print widths). After traffic had been completed over this area, additional traffic was applied to a 64.75-in.-wide area (7 tire-print widths) within the wider area just trafficked. Following completion of this traffic, the cart was moved in to traffic a 46.25-in.-wide area (5 tire-print widths) and then moved in further to traffic a 27.75-in.-wide area (3 tire-print widths).

92. When the test cart was maneuvered from one side of a traffic

lane width to the other, a 3-sec delay time was required to reverse the transverse direction of travel of the cart. During this delay, the cart continued to run, thus making each lane width slightly greater and producing slightly more traffic on the outside edges of each width. Due to this increased traffic, there was a tendency toward subgrade failure along the outside edges of each width of traffic lane.

93. All test items received 1260 coverages over 10 tire-print widths (wheel paths) and then 743 coverages over 7 wheel paths, making a total of 2003 coverages. At this coverage level, item 6 was considered failed due to movement of the membrane on the subgrade, which caused the surface to lose its water resistance.

94. At this time, 1866 additional coverages were applied over the 5-wheel-path-wide area of the traffic lane. Item 7 was considered failed at this coverage level (3869 coverages). Again, failure was caused by movement of the membrane on the subgrade resulting in a nonwaterproof surface.

95. Next, 2750 additional coverages were applied over the 3-wheel-path-wide area of the traffic lane, making a total of 6619 coverages over the entire lane. Item 8 was failed at this time. Failure was caused by movement of the membrane on the subgrade and by holes in the membrane. The holes occurred at wrinkles in the membrane and were caused by traffic wearing away the asphalt surfacing.

96. Traffic was continued, and item 10 sustained 6316 coverages over 3 wheel paths before failure. Thus, item 10 failed at 10,185 coverages due to movement of the membrane on the subgrade.

97. Before failure, item 9 withstood 10,332 coverages over 3 wheel paths, making a total of 14,201 coverages. Cause of failure was movement of the membrane on the subgrade, which destroyed the water-resistant surface.

98. Item 1 sustained a total of 16,551 coverages before failure, 12,682 of which were over the inside 3 wheel paths. Failure was caused by movement of the membrane on the subgrade.

99. Item 2 withstood 21,335 total coverages on the membrane before failure, 17,466 of which were applied over the inside 3 wheel paths.

Once again, failure resulted from movement of the membrane on the subgrade.

100. Item 3 failed because of holes in the membrane. These holes were caused by wearing away of the asphalt surface at wrinkles in the membrane. Item 3 withstood 22,585 total coverages before failure, 18,716 of which were applied over the inside 3 wheel paths.

101. Item 5 had withstood 34,000 total coverages before failure, 30,131 of which were applied over the inside 3 wheel paths. The cause of failure in item 5 was the same as that in item 3.

102. Item 4 sustained 55,836 total coverages (51,967 over inside 3 wheel paths) without failing.

103. Traffic test results and the mode of failure for each item are given in table 2.

Conclusions

104. Based on the results of the tests described above, the following conclusions are believed warranted:

- a. The test facility is a vast improvement over facilities previously used for fatigue tests of membranes and pavements.
- b. Of the membranes tested, both single and double layers of product D sustained the greatest number of coverages, followed by single and double layers of products E, C, B, and A, in that order.
- c. Considering the performance characteristics listed in table 2, product D again performed best, followed by products E, A, B, and C, in that order.
- d. A single layer of membrane performs better than a double layer.
- e. Nonwoven membranes perform better than woven membranes.
- f. Generally, nonwoven membranes are easier to apply than woven membranes.
- g. Nonwoven membranes absorb more asphalt than woven membranes.
- h. Nonwoven membranes wrinkle less than woven membranes.
- i. Nonwoven membranes have better bond to the subgrade than woven membranes.

PART VI: SUMMARY AND RECOMMENDATIONS

Summary

105. This investigation was based on the need to develop new road building techniques to reduce the construction time and costs of military roads. In many instances, sizable construction effort and costs are required to obtain materials and produce the high-strength foundation layers required in military roads. The investigation involved developing construction techniques and procedures for employing an MESL as a base course to allow rapid road construction. The objectives were accomplished in four separate phases as follows:

a. Phase I: Development of Earth-Handling Techniques. Construction methods for encapsulating fine-grained soil in waterproof membrane were developed. This was accomplished through the study of earthwork-handling techniques and involved the determination of the most efficient means of utilizing equipment and personnel to construct an MESL roadway. The results of the work conducted under this phase of the project are presented in a separate report.[5]

b. Phase II: Development of Minimum Construction Requirements. A test road was built containing different strength MESL bases and various conventional base courses. Traffic tests were conducted and comparative data were obtained. It was established that compaction of a full 12-in. MESL of fine-grained soil to 95 percent of CE 12 density (MIL-STD-621A, Method 100) is sufficient to support traffic operations of a 5-ton, 6x6 military dump truck loaded to its maximum weight for highway travel. Water content of the soil should be at or below optimum during construction; preferably, it should be slightly below optimum.

c. Phase III: Demonstration Road Construction and Performance. A test road was constructed using MESL construction techniques to serve as a demonstration road for the MESL concept. It was laid out in the shape of a figure eight to incorporate curves and an intersection. Also, a hillside was included as part of the road. The performance of the 1600-ft-long road from July-December 1970 was good. Intermittent traffic, using a fully loaded 5-ton military truck, caused negligible damage

to the road except at the intersection. Here, the cross-type traffic pattern was beginning to break the bond between the upper membrane and the soil surface. An unusually heavy rainfall occurred during October, and most of the demonstration road was submerged. The flooding severely tested the waterproofness of the MESL road. Only one localized failure resulted from the flood.

d. Phase IV: Test Facility for Evaluating Military Road Surfacings. A test facility was designed and constructed for the purpose of rapidly evaluating membrane materials and other surfacings for military roads. Several membranes were tested at the new facility. Polypropylene fabrics, both woven and nonwoven, were tested in single and double layer membranes. The best performance was obtained from a membrane which contained a single layer of nonwoven fabric. This membrane survived over 50,000 coverages of dual-wheel traffic (loaded to slightly more than the maximum highway load for 5-ton military trucks) and remained waterproof.

Recommendations

106. Based on the results of this investigation the following recommendations are made:

a. A demonstration MESL road should be constructed by troops under conditions similar to those in the TO. If the benefits of the research developed under this project are to be realized, a demonstration road constructed by field troops is necessary to validate the MESL concept or point out any problem areas that may need further development.

b. Further testing should be conducted at the WES circular test facility to improve the waterproof membranes used in MESL construction. Membranes containing new fabrics and liquid asphalts other than the one used in this investigation should be studied.

c. Since membrane placement around curves must be done in sections and by hand placement, new approaches should be studied.

(1) Use chopped fabric and blow into place rather than hand place sections of fabric.

(2) Explore forming the top membrane from the in-place soil and a binding or cementing agent. This might

require pulverizing the top inch or so of the soil and spraying the binding agent and rolling.

d. Field test a number of pavement surfacing materials for placement on MESL foundations to determine surfacing requirements for various categories of military roads. Various thicknesses of hot-mix asphaltic concrete and bituminous surface treatments should be investigated.

e. Further testing should be conducted to establish requirements on when or when not to use a lower membrane. In some instances, when good drainage can be established, the use of only a surface membrane or compacted subgrade soil might provide the same benefits as an MESL or conventional foundation.

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Table 1

Phase II Test Road Data

Test Item	Surface Description	CBR	Water Content %	Dry Density pcf	Coverages*	Remarks
1	2 in. of hot-mix asphaltic concrete					
	Subgrade conditions	6	21	84	--	--
	Encapsulated-soil conditions	--	--	--	--	--
	Dry traffic lane	--	--	--	900	Failed
	Wet traffic lane					
	Wet-shoulder conditions	--	--	--	900	Failed
	Flooded-lane conditions	--	--	--	--	--
2	4 in. of hot-mix asphaltic concrete					
	Subgrade conditions	6	21	84	--	--
	Encapsulated-soil conditions	--	--	--	--	--
	Dry traffic lane	--	--	--	3000	Two localized failures; overall condition good
	Wet traffic lane					
	Wet-shoulder conditions	--	--	--	3000	One localized failure; overall condition good
	Flooded-lane conditions	--	--	--	1200	One localized failure; overall condition good
3	12 in. of compacted clay gravel					
	Subgrade conditions	6	21	84	--	--
	Encapsulated-soil conditions	--	--	--	--	--
	Dry traffic lane	--	--	--	3000	One localized failure; overall condition good
	Wet traffic lane					
	Wet-shoulder conditions	--	--	--	3000	One localized failure; overall condition good
	Flooded-lane conditions	--	--	--	36	Failed along outside wheel path
4	12 in. of lime-stabilized lean clay					
	Subgrade conditions	6	21	84	--	--
	Encapsulated-soil conditions	--	--	--	--	--
	Dry traffic lane	--	--	--	3000	No damage
	Wet traffic lane					
	Wet-shoulder conditions	--	--	--	3000	No damage
	Flooded-lane conditions	--	--	--	348	Failed along outside wheel path
5	12 in. of cement-stabilized lean clay					
	Subgrade conditions	6	21	84	--	--
	Encapsulated-soil conditions	--	--	--	--	--
	Dry traffic lane	--	--	--	3000	No damage
	Wet traffic lane					
	Wet-shoulder conditions	--	--	--	3000	No damage
	Flooded-lane conditions	--	--	--	1200	No damage
6	12 in. of encapsulated soil					
	Subgrade conditions	6	21	84	--	--
	Encapsulated-soil conditions	13	14	94	--	--
	Dry traffic lane	26	14	96	3000	No damage

(Continued)

* One pass of 5-ton, 6x6 military truck with maximum highway loading is equal to three coverages of 5000-lb ESWL.

Table 1 (Concluded)

Test Item	Surface Description	CBR	Water Content %	Dry Density pcf	Coverages	Remarks
6 (Cont'd)	Wet traffic lane					
	Wet-shoulder conditions	26	14	96	3000	No damage
	Flooded-lane conditions	--	--	--	1200	Negligible damage
7	12 in. of encapsulated soil					
	Subgrade conditions	6	21	84	--	--
	Encapsulated-soil conditions	10	14	90	--	--
	Dry traffic lane	25	14	93	3000	No damage
	Wet traffic lane					
	Wet-shoulder conditions	26	14	96	3000	One localized failure: overall condition good
	Flooded-lane conditions	--	--	--	480	Failed along outside wheel path
8	12 in. of encapsulated soil					
	Subgrade conditions	6	21	84	--	--
	Encapsulated-soil conditions	14	12	93	--	--
	Dry traffic lane	27	13	96	3000	No damage
	Wet traffic lane					
	Wet-shoulder conditions	27	14	96	3000	One localized failure; overall condition good
	Flooded-lane conditions	--	--	--	1200	No damage
9	12 in. of encapsulated soil					
	Subgrade conditions	6	21	84	--	--
	Encapsulated-soil conditions	8	12	88	--	--
	Dry traffic lane	24	13	91	3000	No damage
	Wet traffic lane					
	Wet-shoulder conditions	24	14	93	3000	No damage
	Flooded-lane conditions	--	--	--	450	Failed along outside wheel path
10	12 in. of encapsulated soil					
	Subgrade conditions	6	21	84	--	--
	Encapsulated-soil conditions	19	6	86	--	--
	Dry traffic lane	24	7	87	3000	Significant rutting; failure imminent
	Wet traffic lane					
	Wet-shoulder conditions	19	6	87	3000	Significant rutting; condition poor
	Flooded-lane conditions	--	--	--	288	Failed along outside wheel path with rutting along inside wheel path
11	12 in. of encapsulated soil					
	Subgrade conditions	6	21	84	--	--
	Encapsulated-soil conditions	11	6	86	--	--
	Dry traffic lane	18	7	89	900	Failed due to rutting
	Wet traffic lane					
	Wet-shoulder conditions	22	6	89	900	Failed due to rutting
	Flooded-lane conditions	--	--	--	--	--

Table 2

Comparison of Performance Characteristics of Membranes Under Traffic

Item	Membrane: Product	Membrane: Type of Fabric	Membrane: No. of Layers on Section	Traffic Pattern: Wheel Paths	Traffic Pattern: No. Coverages	Total Coverages	Performance Characteristics*: Ease of Application	Performance Characteristics*: Asphalt Absorption	Performance Characteristics*: Subgrade Bond	Performance Characteristics*: Wrinkles	Mode of Failure
1	A	Woven	1	10 7 5 3	1,260 743 1,866 12,682	16,551	1	3	4	3	Movement of membrane on subgrade
2	B	Woven	1	10 7 5 3	1,260 743 1,866 17,466	21,335	4	4	5	4	Movement of membrane on subgrade
3	C	Woven, butyl-coated	1	10 7 5 3	1,260 743 1,866 18,716	22,585	5	5	3	5	Holes at wrinkles
4	D	Nonwoven	1	10 7 5 3	1,260 743 1,866 51,967	55,836	2	1	1	1	Did not fail
5	E	Nonwoven	1	10 7 5 3	1,260 743 1,866 30,131	34,000	3	2	2	2	Holes at wrinkles
6	A	Woven	2	10 7	1,260 743	2,003	1	3	5	3	Movement of membrane on subgrade
7	B	Woven	2	10 7 5	1,260 743 1,866	3,869	4	4	4	4	Movement of membrane on subgrade
8	C	Woven, butyl-coated	2	10 7 5 3	1,260 743 1,866 2,750	6,619	5	5	3	5	Movement of membrane on subgrade and holes at wrinkles
9	D	Nonwoven	2	10 7 5 3	1,260 743 1,866 10,332	14,201	2	1	1	1	Movement of membrane on subgrade
10	E	Nonwoven	2	10 7 5 3	1,260 743 1,866 6,316	10,185	3	2	2	2	Movement of membrane on subgrade

* The number 1 represents the best in comparative performance, and 5 represents the poorest; 2, 3, and 4 are indicative of intermediate levels of performance.

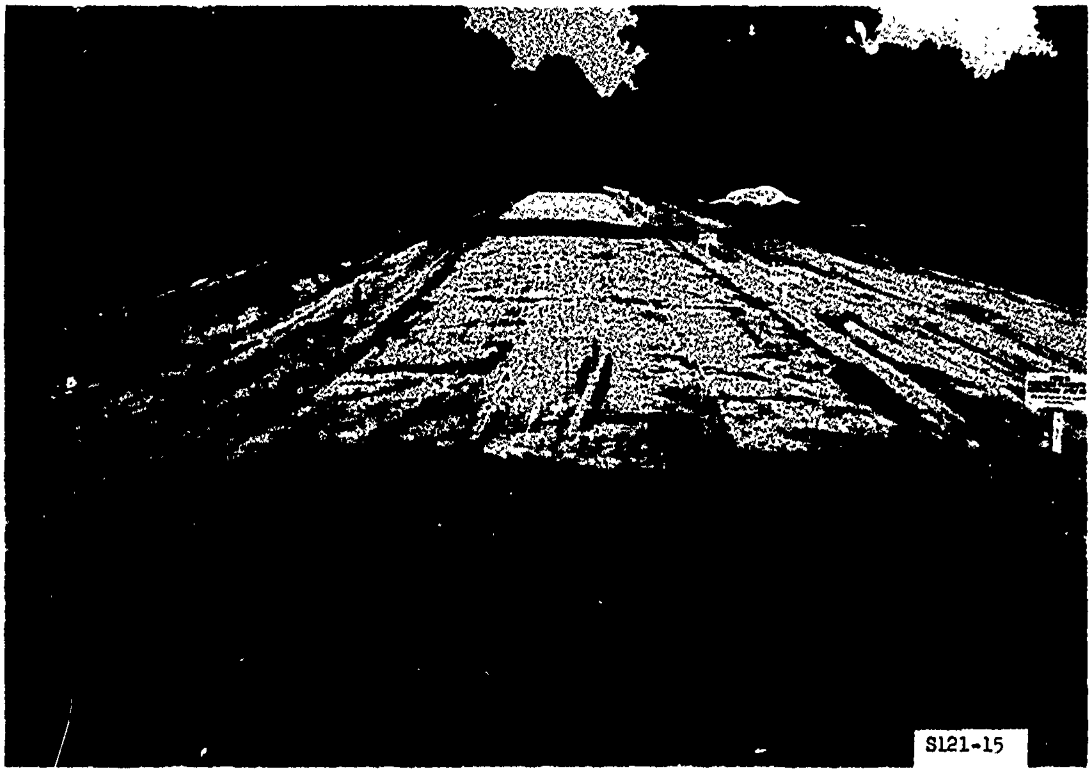


Photo 1. Completed test road prior to trafficking under dry-lane test conditions

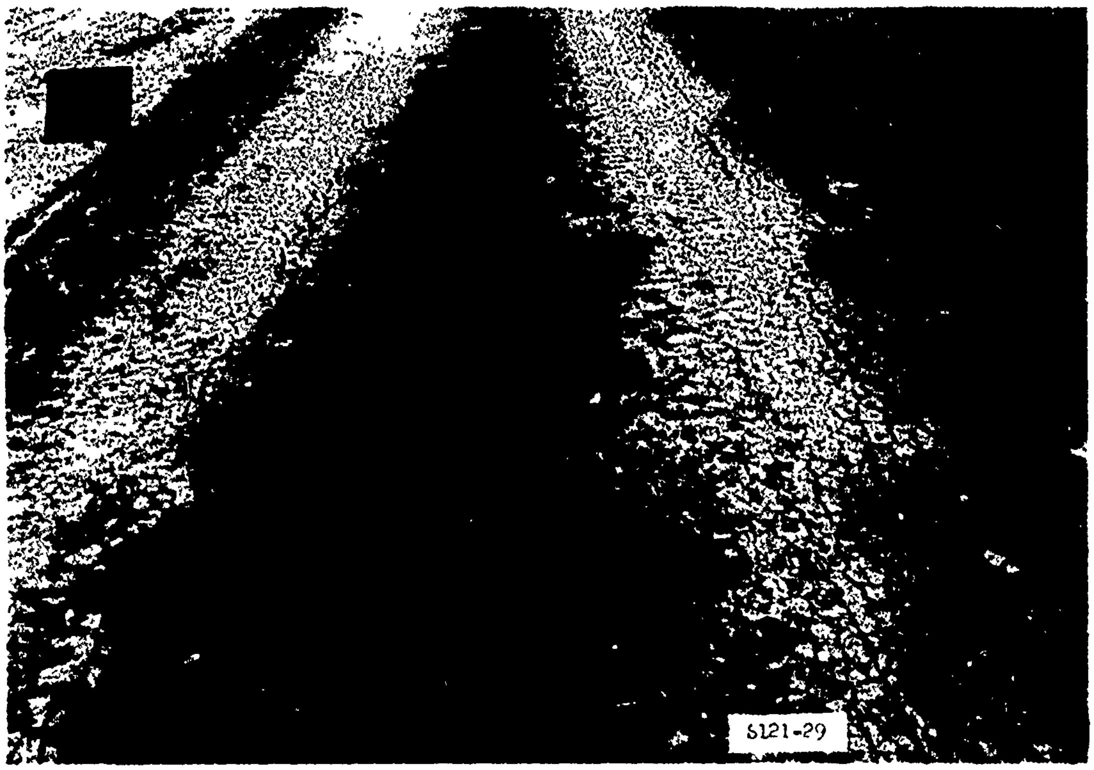


Photo 2. Item 1 after 900 coverages under dry-lane test conditions

Photo 3. Item 11 after 900 coverages under dry-lane test conditions

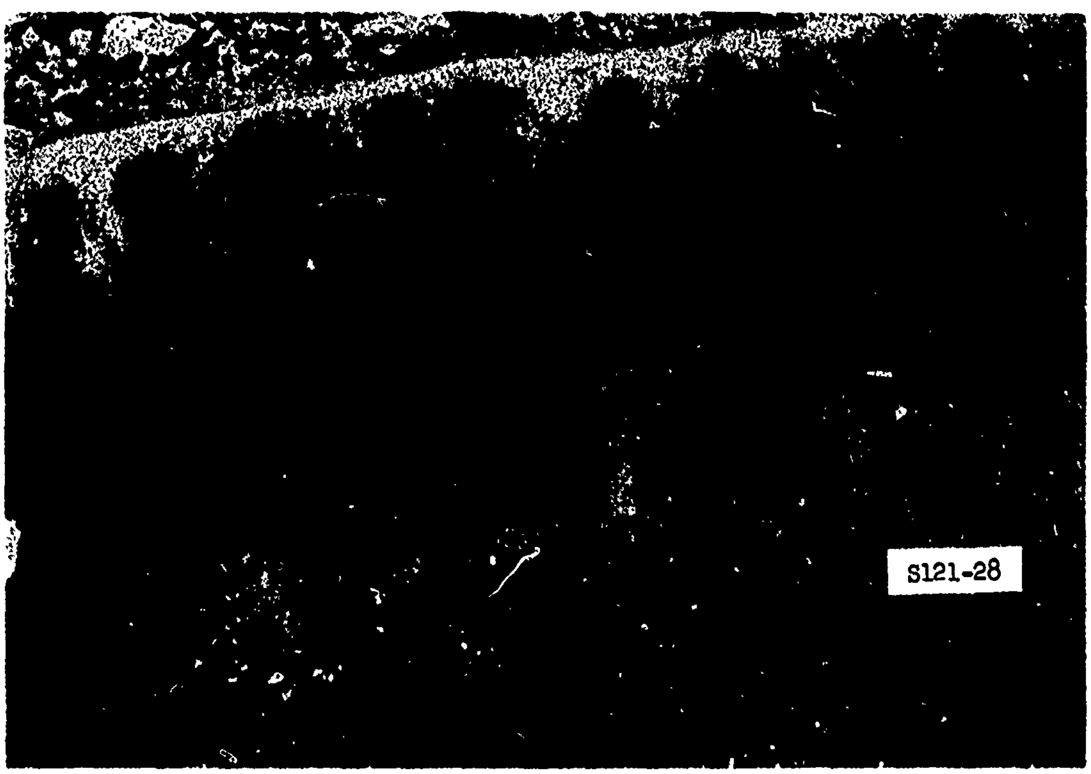


Photo 4. Sheared membrane in item 11 after 900 coverages under dry-lane test conditions

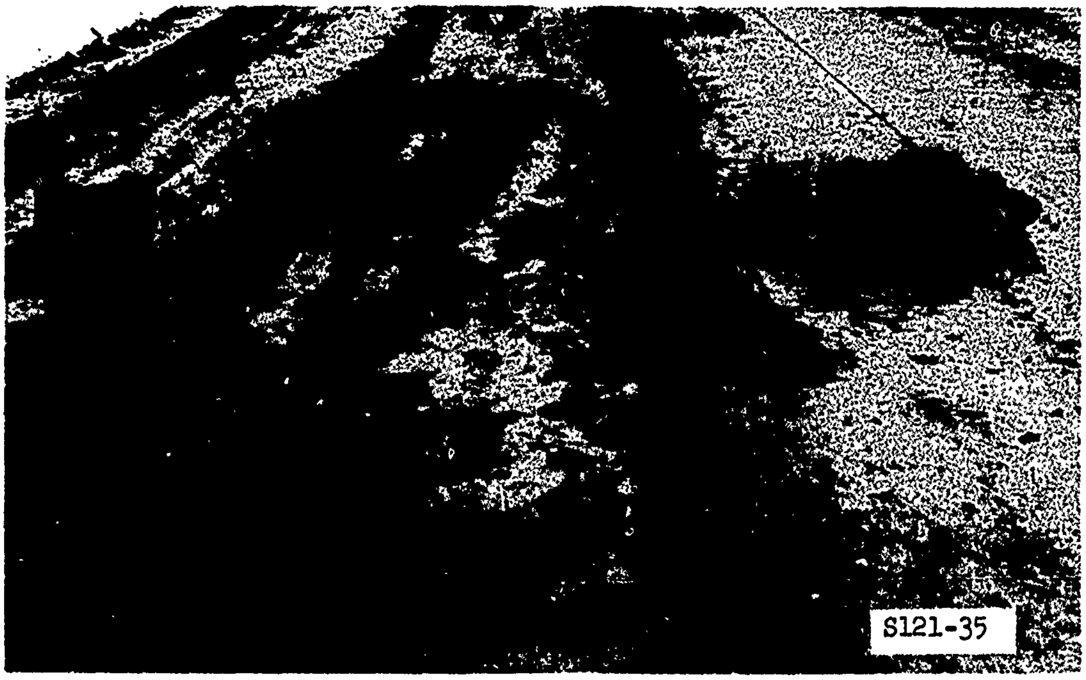


Photo 5. Item 2 after 3000 coverages under dry-lane test conditions

Photo 6. Item 3 after 1275 coverages under dry-lane test conditions

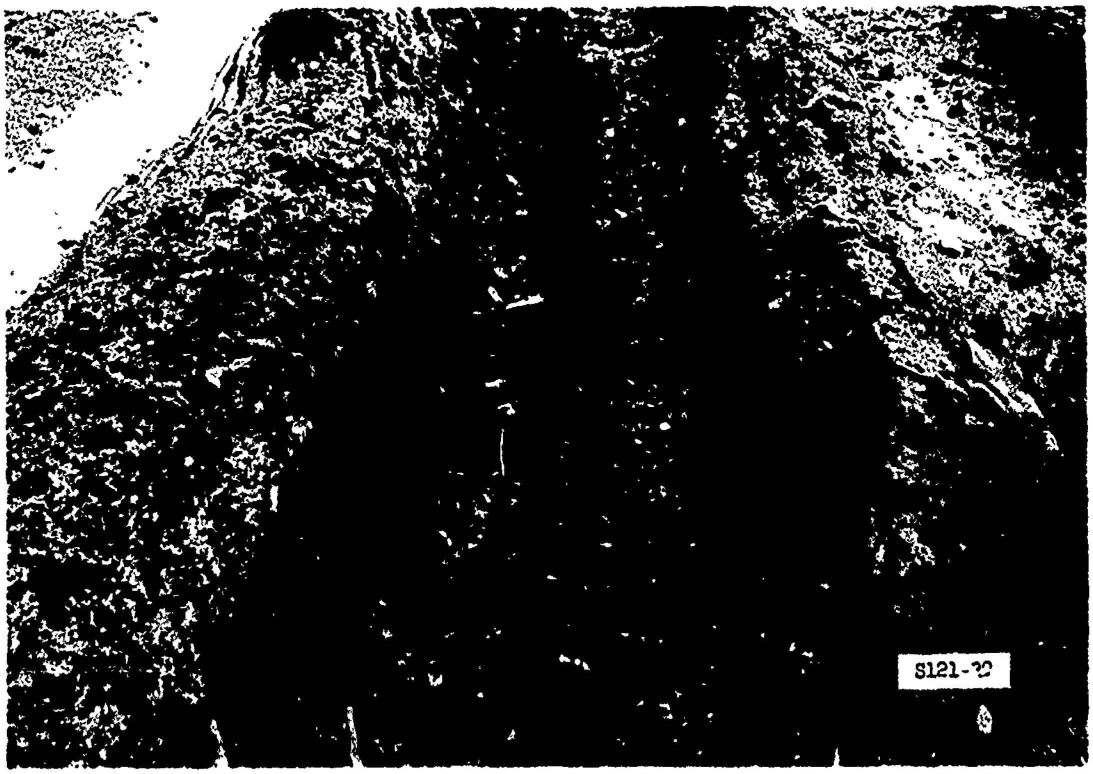


Photo 7. Severe localized failure in item 3 after 1275 coverages under dry-lane test conditions

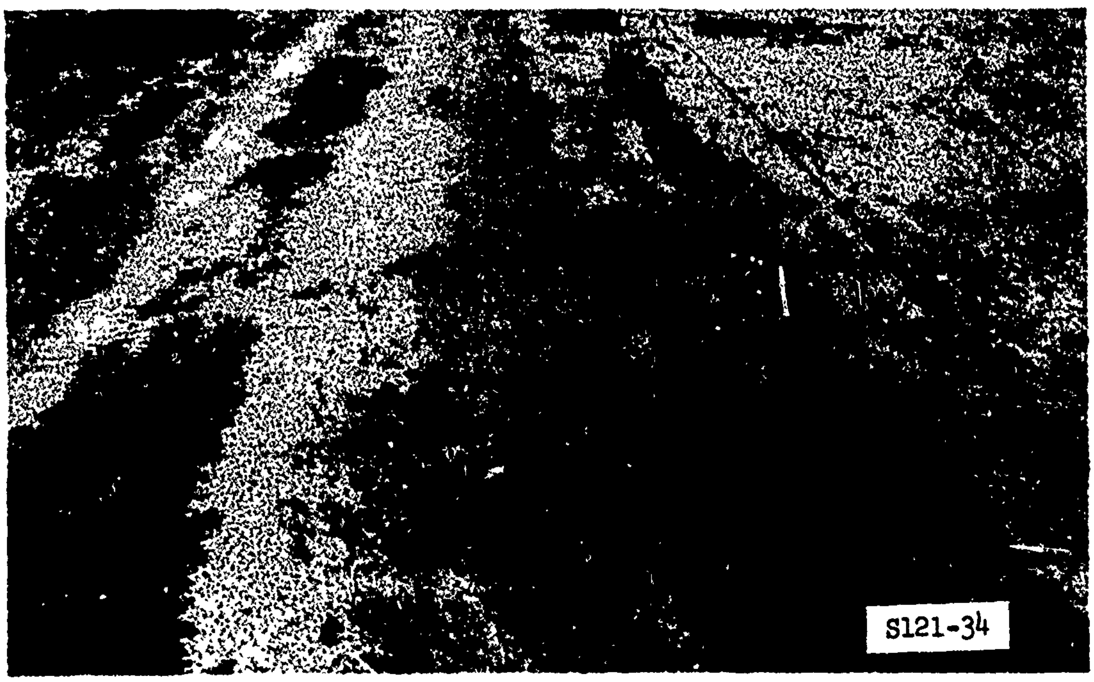


Photo 8. Item 4 after 3000 coverages under dry-lane test conditions

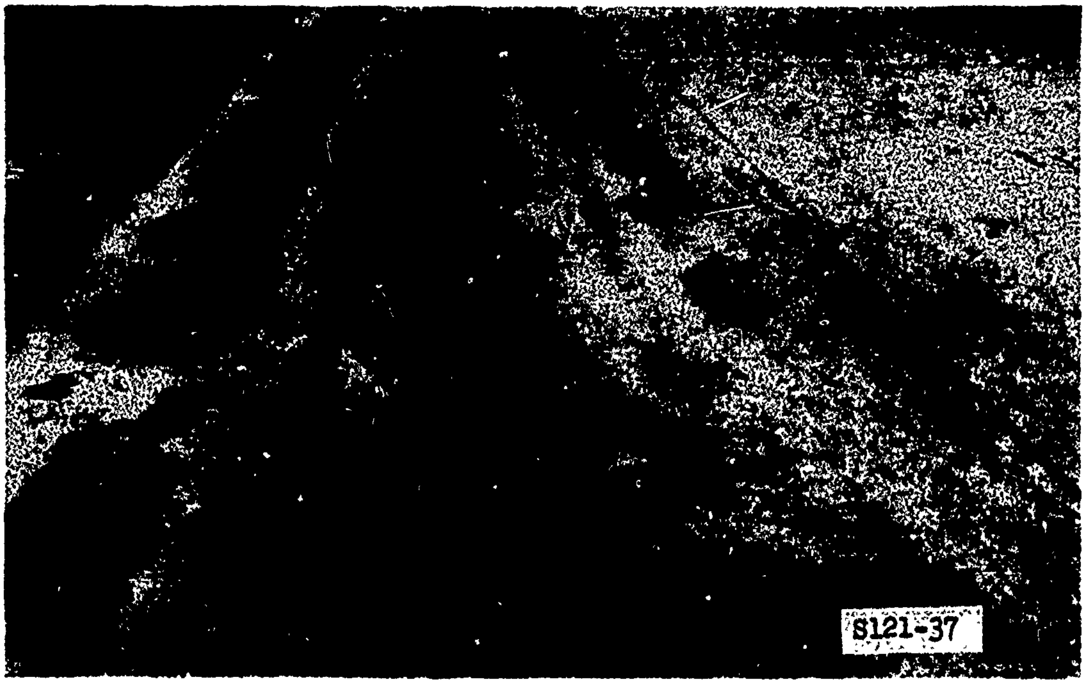


Photo 9. Item 5 after 3000 coverages under dry-lane test conditions

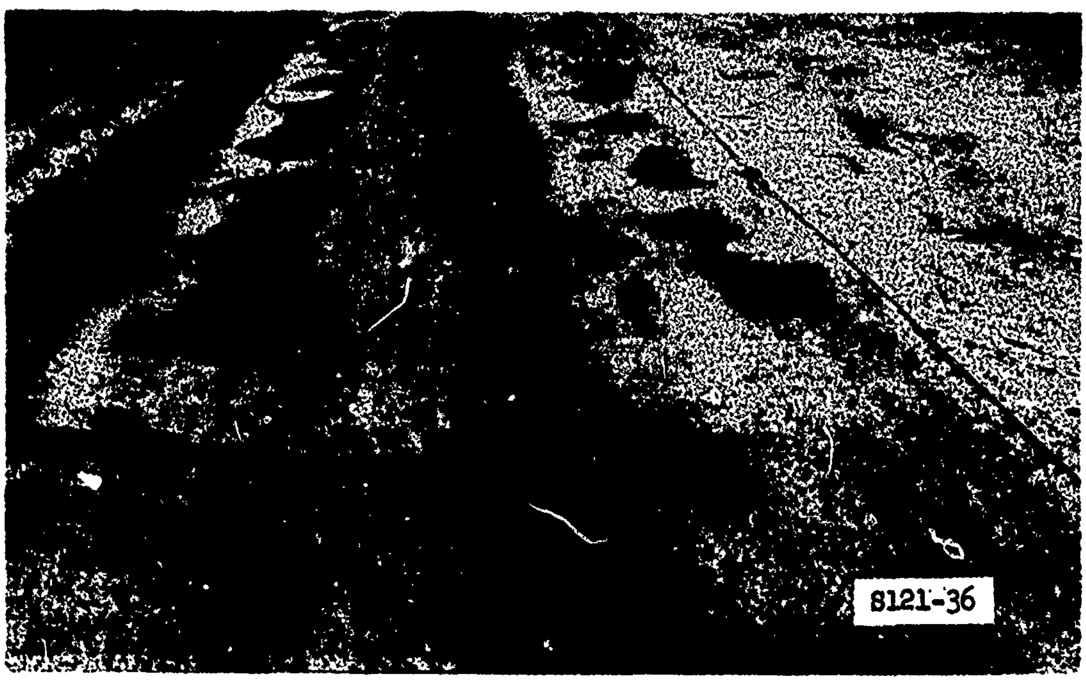


Photo 10. Item 6 after 3000 coverages under dry-lane test conditions

Photo 11. Item 7 after 3000 coverages under dry-lane test conditions

Photo 12. Item 8 after 3000 coverages under dry-lane test conditions

Photo 13. Item 9 after 3000 coverages under dry-lane test conditions

Photo 14. Item 10 after 3000 coverages under dry-lane test conditions

Photo 15. Items 1-5 during wet-shoulder traffic tests

Photo 16. Items 6-11 during wet-shoulder traffic tests

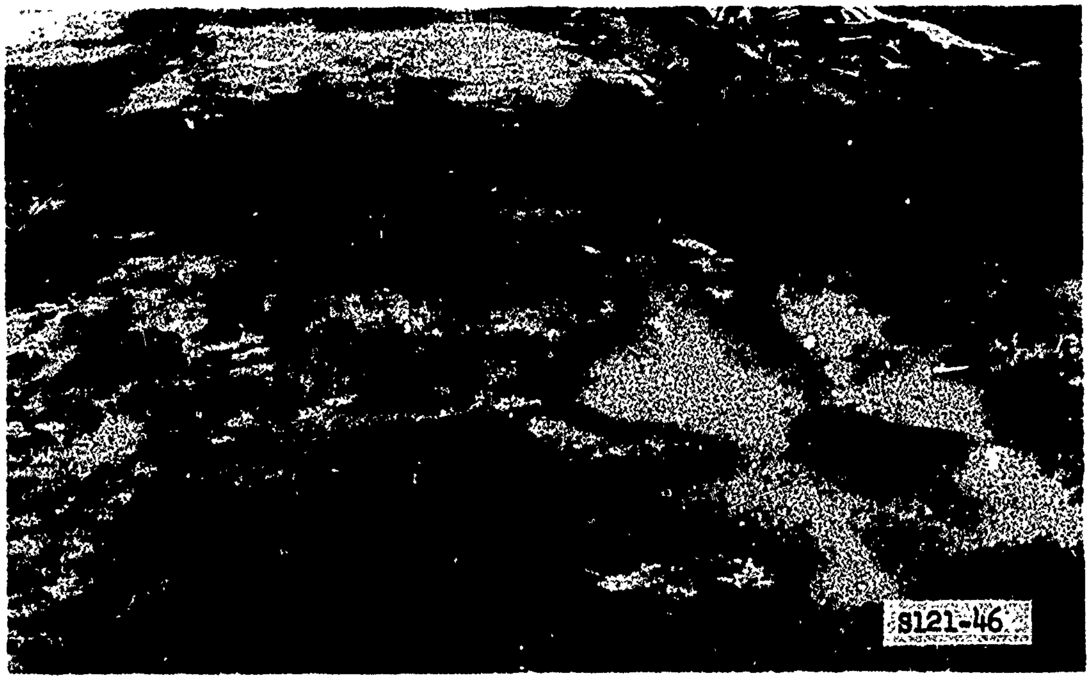


Photo 17. Item 2 after 3000 coverages under wet-shoulder test conditions

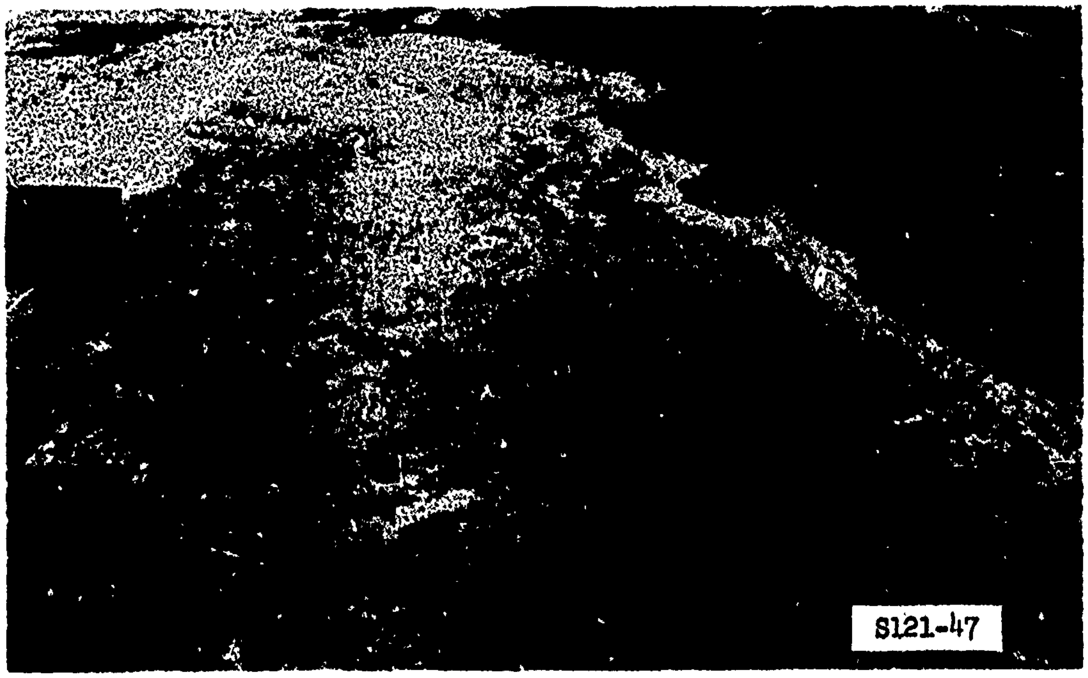


Photo 18. Item 3 after 3000 coverages under wet-shoulder test conditions

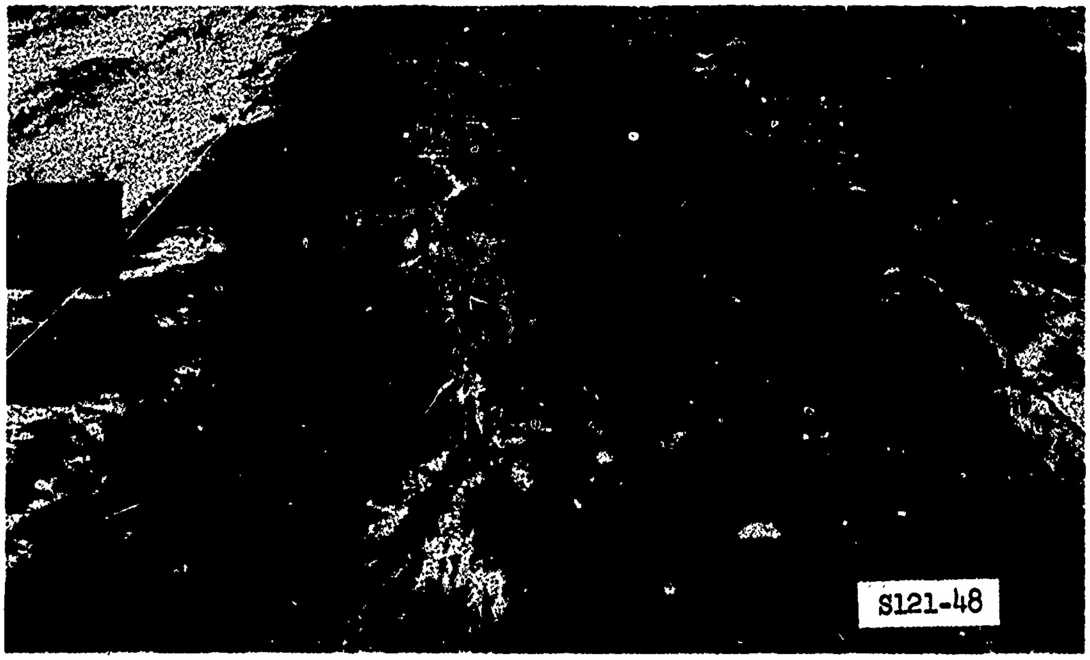


Photo 19. Item 4 after 3000 coverages under wet-shoulder test conditions

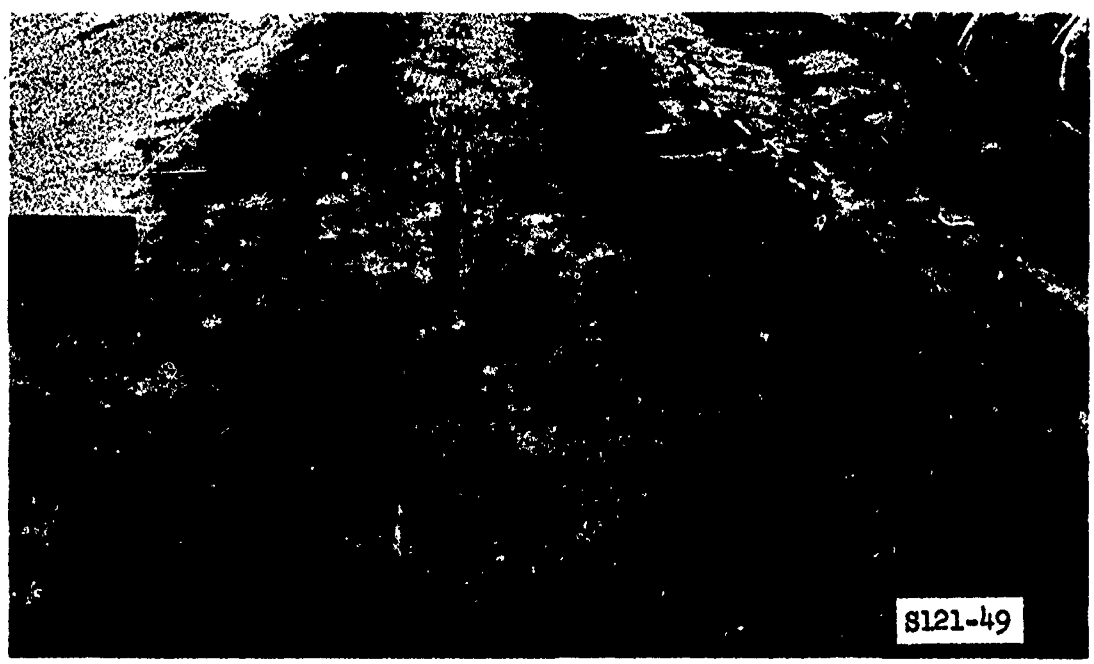


Photo 20. Item 5 after 3000 coverages under wet-shoulder test conditions

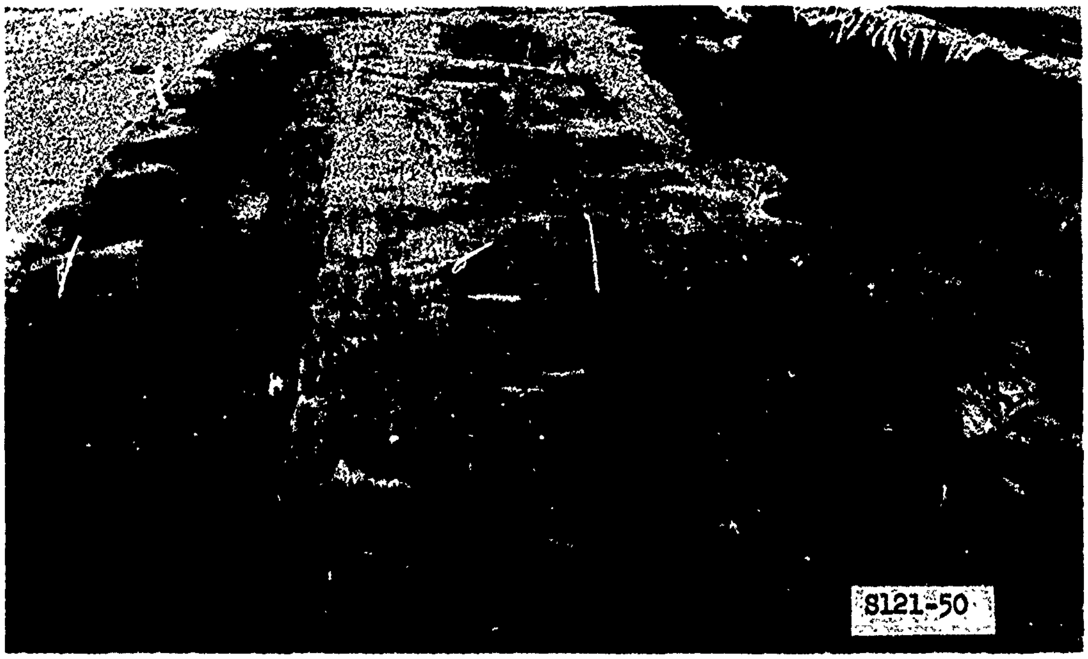


Photo 21. Item 6 after 3000 coverages under wet-shoulder test conditions

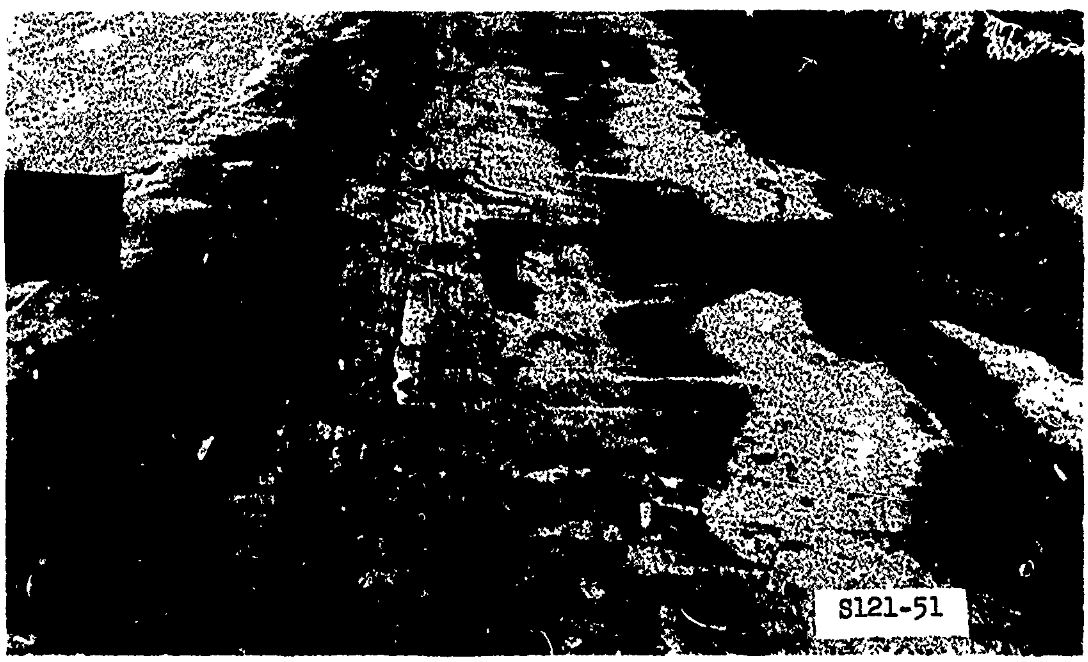


Photo 22. Item 7 after 3000 coverages under wet-shoulder test conditions

Photo 23. Item 8 after 3000 coverages under wet-shoulder test conditions

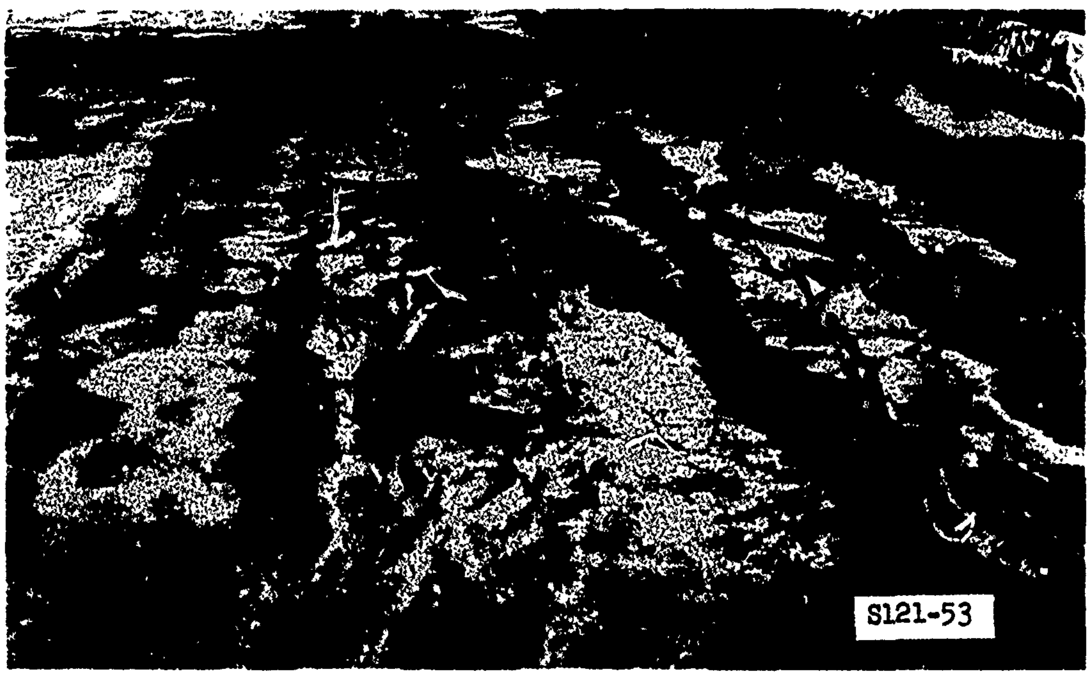


Photo 24. Item 9 after 3000 coverages under wet-shoulder test conditions

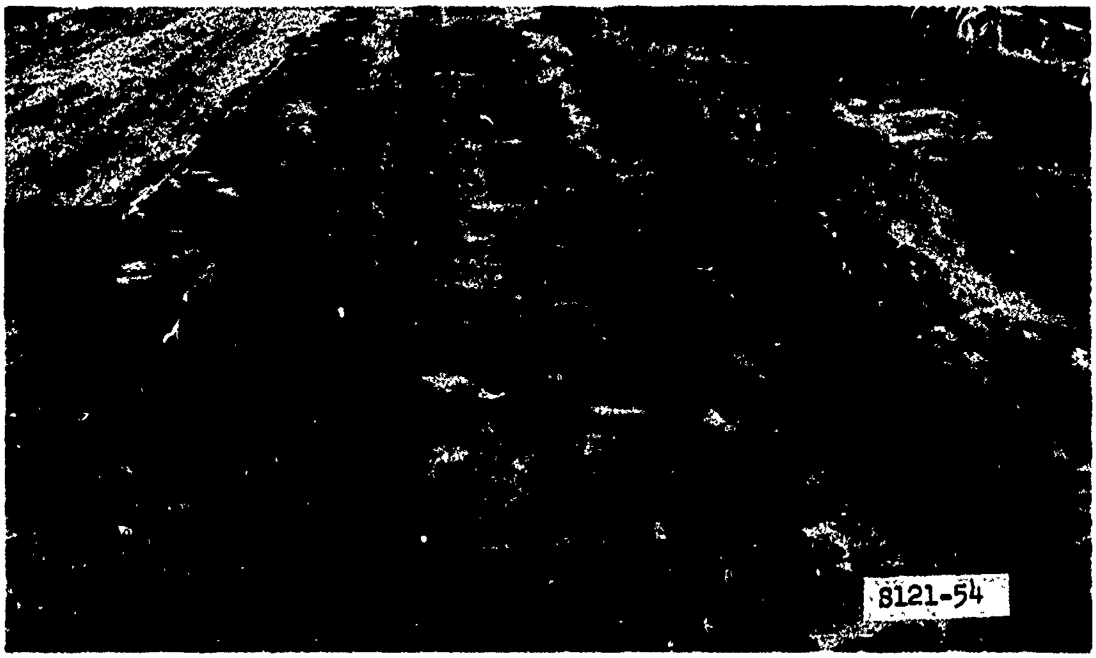


Photo 25. Item 10 after 3000 coverages under wet-shoulder test conditions

Photo 26. Item 2 after 1200 coverages under flooded-lane test conditions

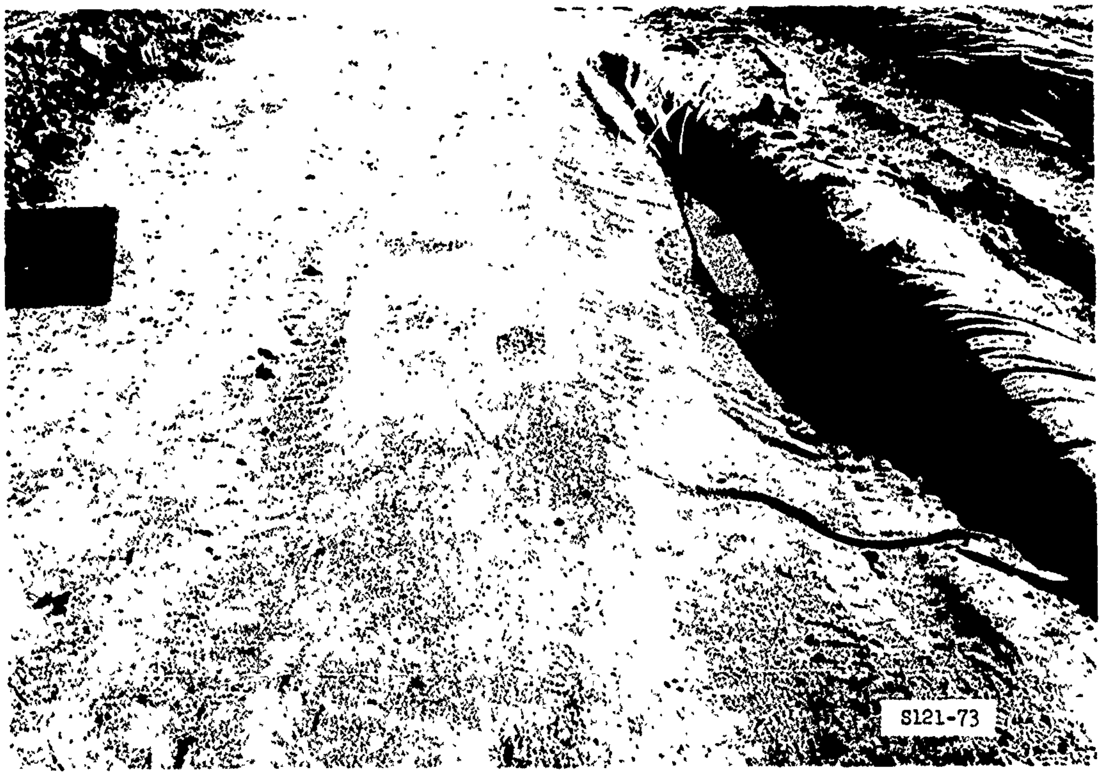


Photo 27. Item 3 after 36 coverages under flooded-lane test conditions

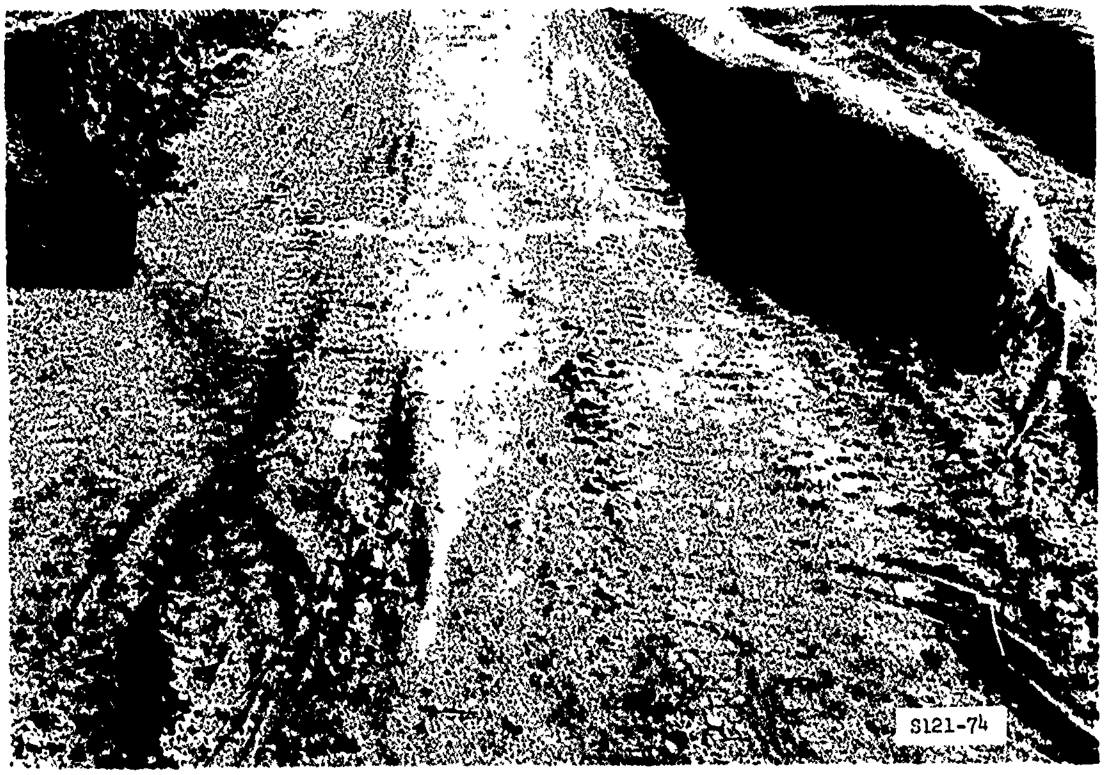


Photo 28. Item 4 after 348 coverages under flooded-lane test conditions

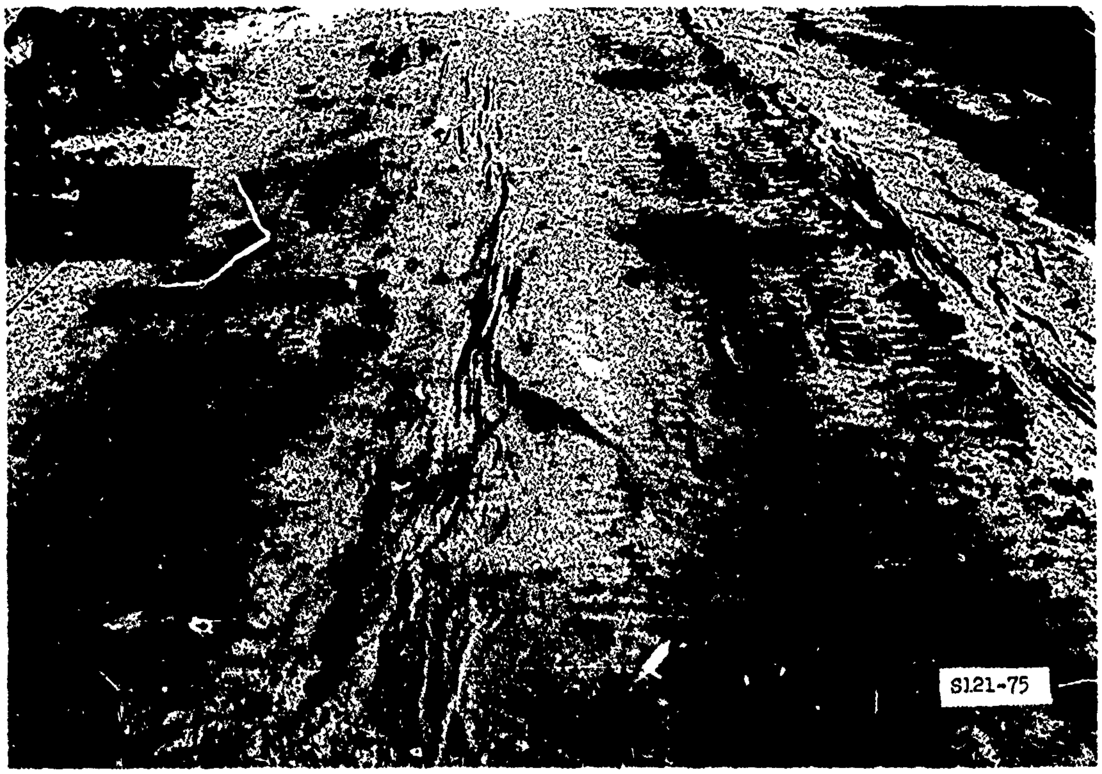


Photo 29. Item 5 after 1200 coverages under flooded-lane test conditions

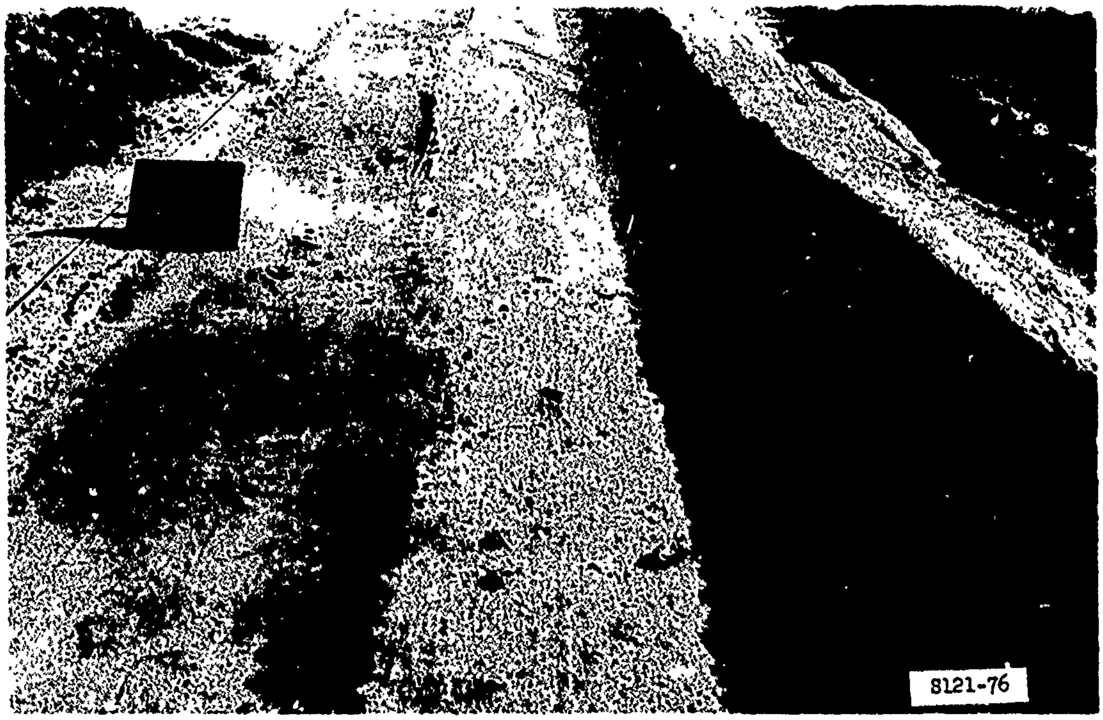


Photo 30. Item 6 after 1200 coverages under flooded-lane test conditions

Photo 31. Item 7 after 480 coverages under flooded-lane test conditions

Photo 32. Item 8 after 1200 coverages under flooded-lane test conditions

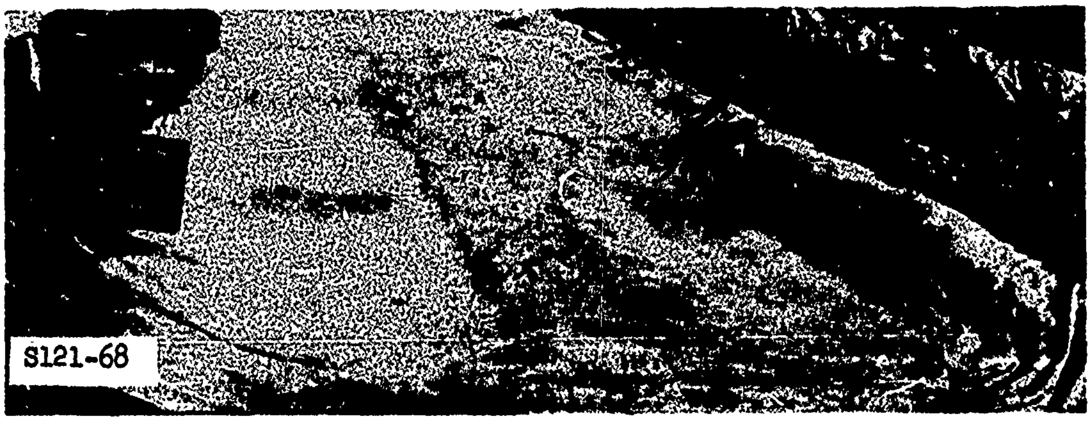


Photo 33. Item 9 after 450 coverages under flooded-lane test conditions

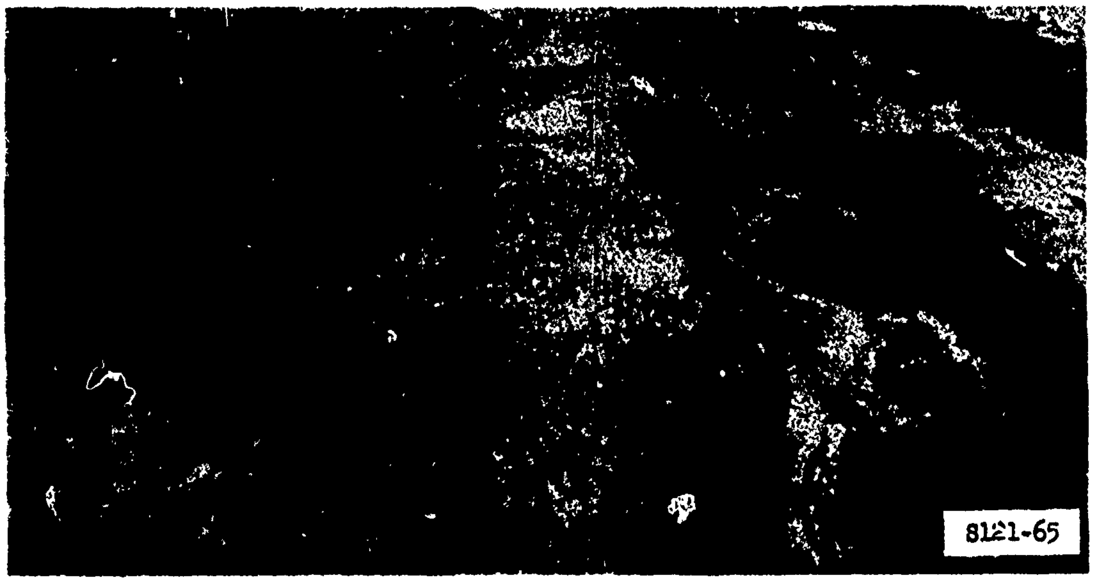


Photo 34. Item 10 after 288 coverages under flooded-lane test conditions

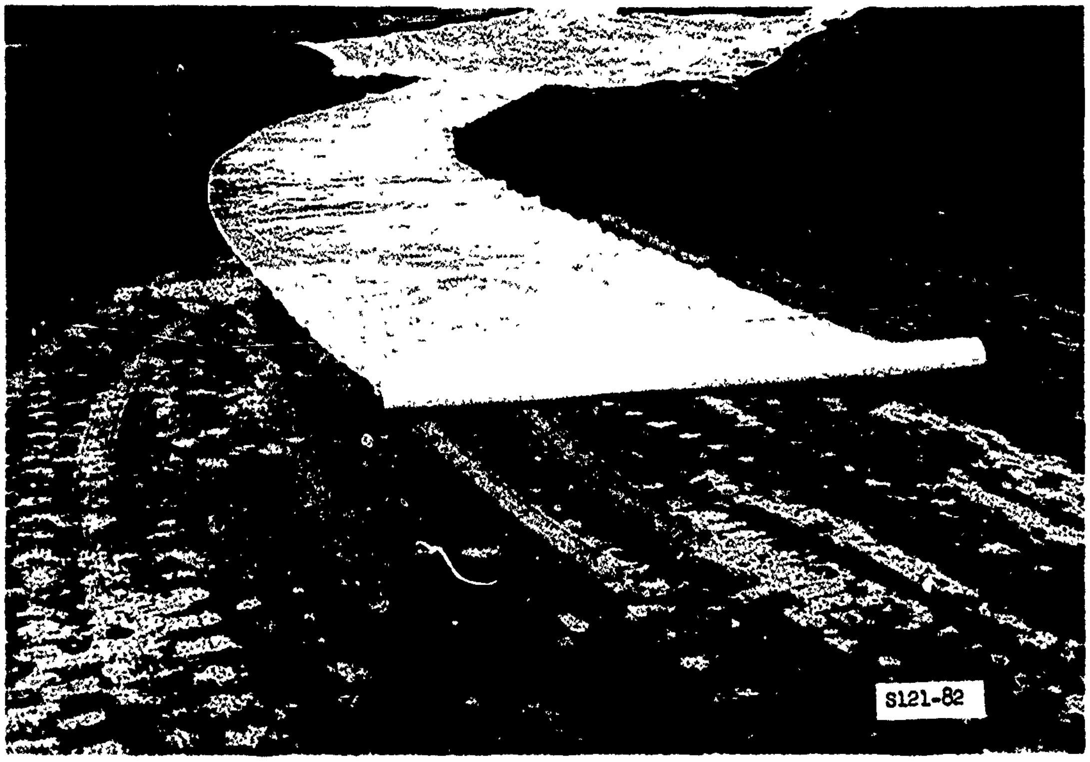


Photo 35. Lower membrane placement (note shoulder material on each side of roadbed)

Photo 36. Earth installation

Photo 37. Spreading soil on lower membrane

Photo 38. Exposed lower membrane in anchor ditch

Photo 39. Upper membrane installation on first half of road

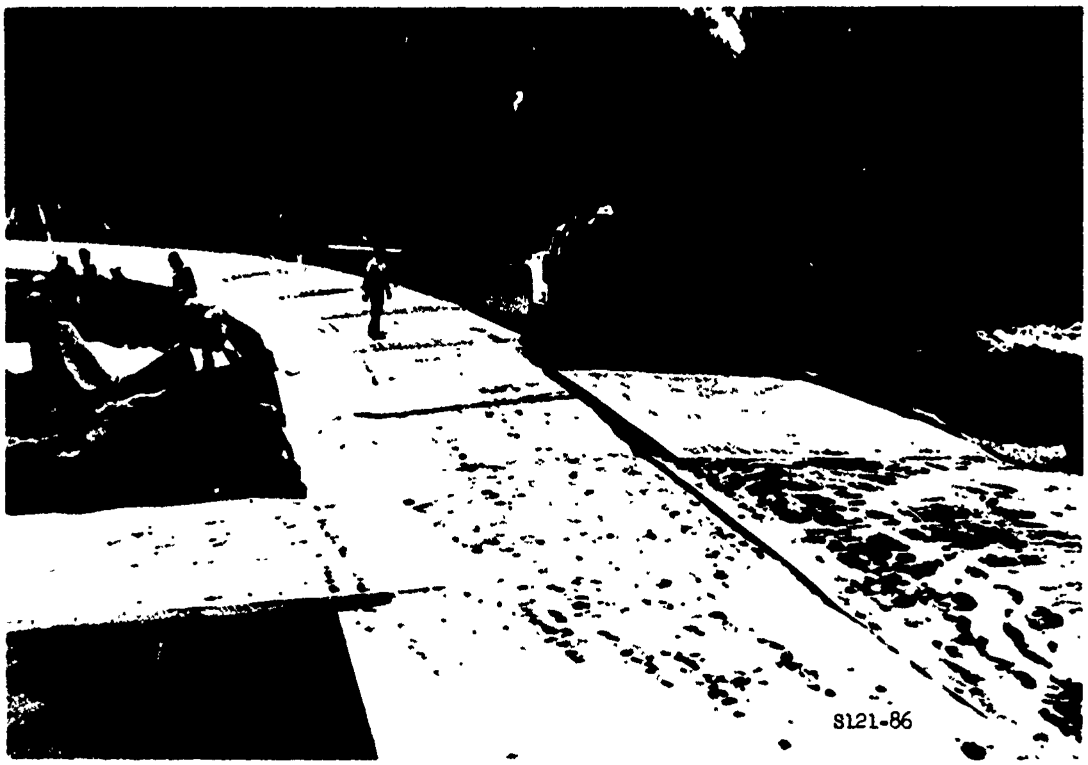


Photo 40. Upper membrane installation on second half of road

Photo 41. Spraying asphalt onto upper membrane surface

Photo 42. Applying sand blotter

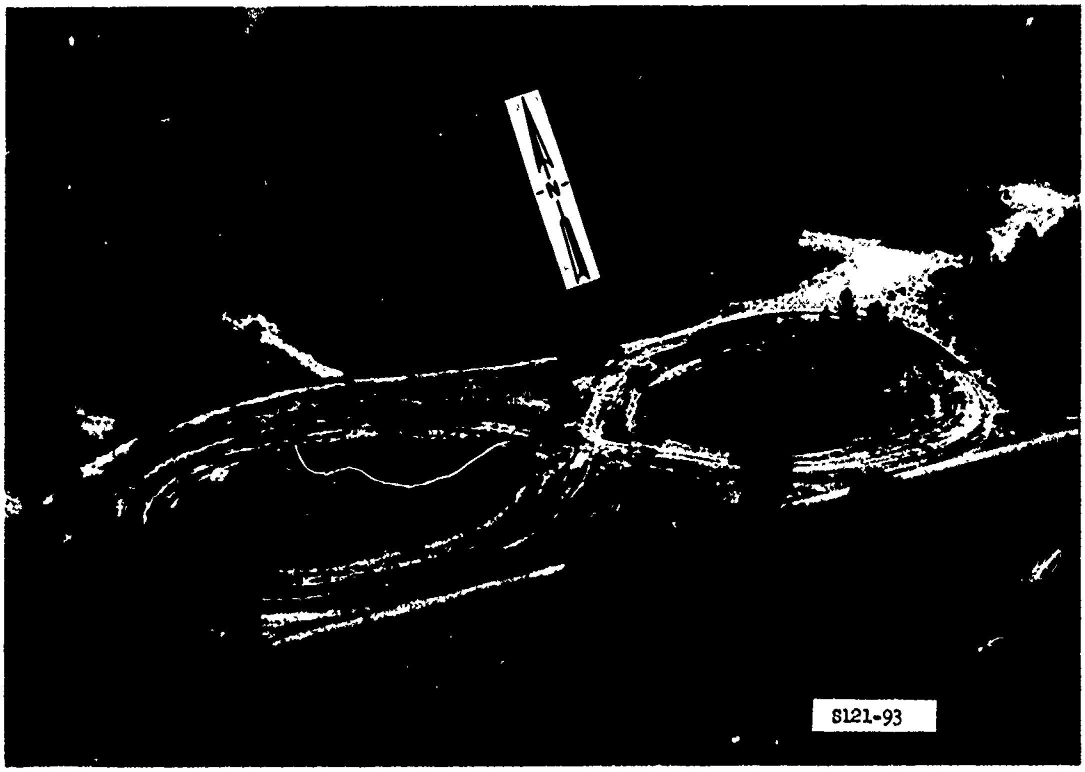


Photo 43. Phase III demonstration road prior to traffic tests

Photo 44. Traffic on flat portion of demonstration road

Photo 45. Traffic on 14.8 percent grade

Photo 46. Test road as seen from hill at sta 7+00 during flood

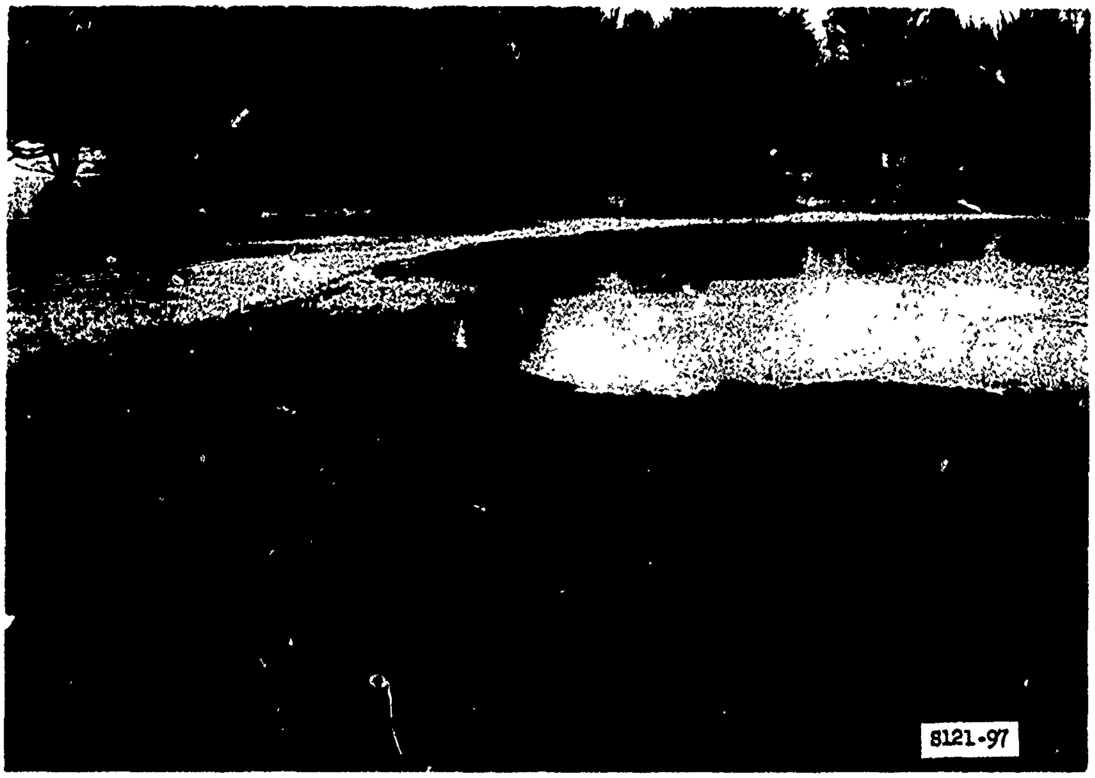
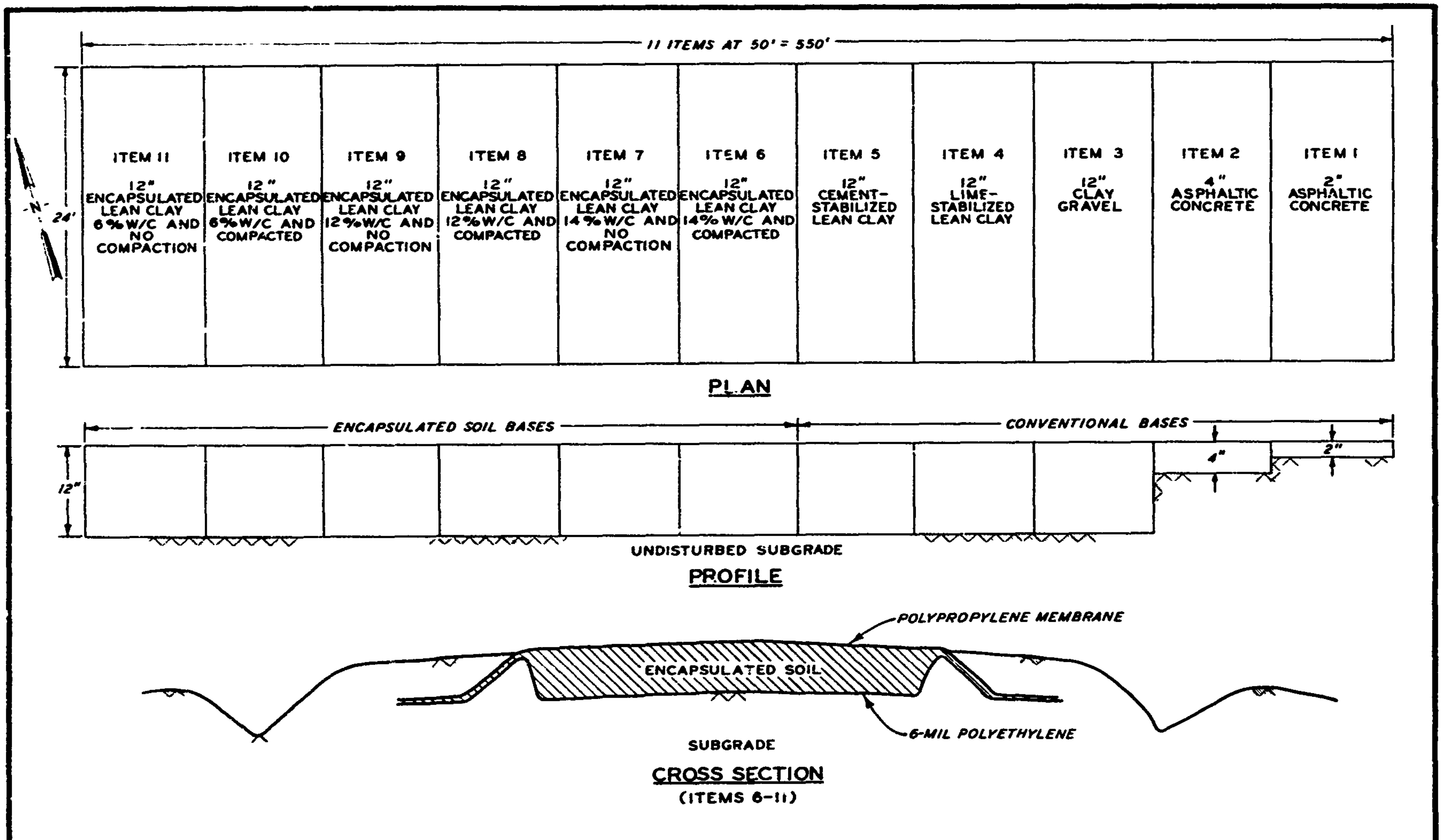


Photo 47. Test road from sta 8+00 to 10+50 during flood

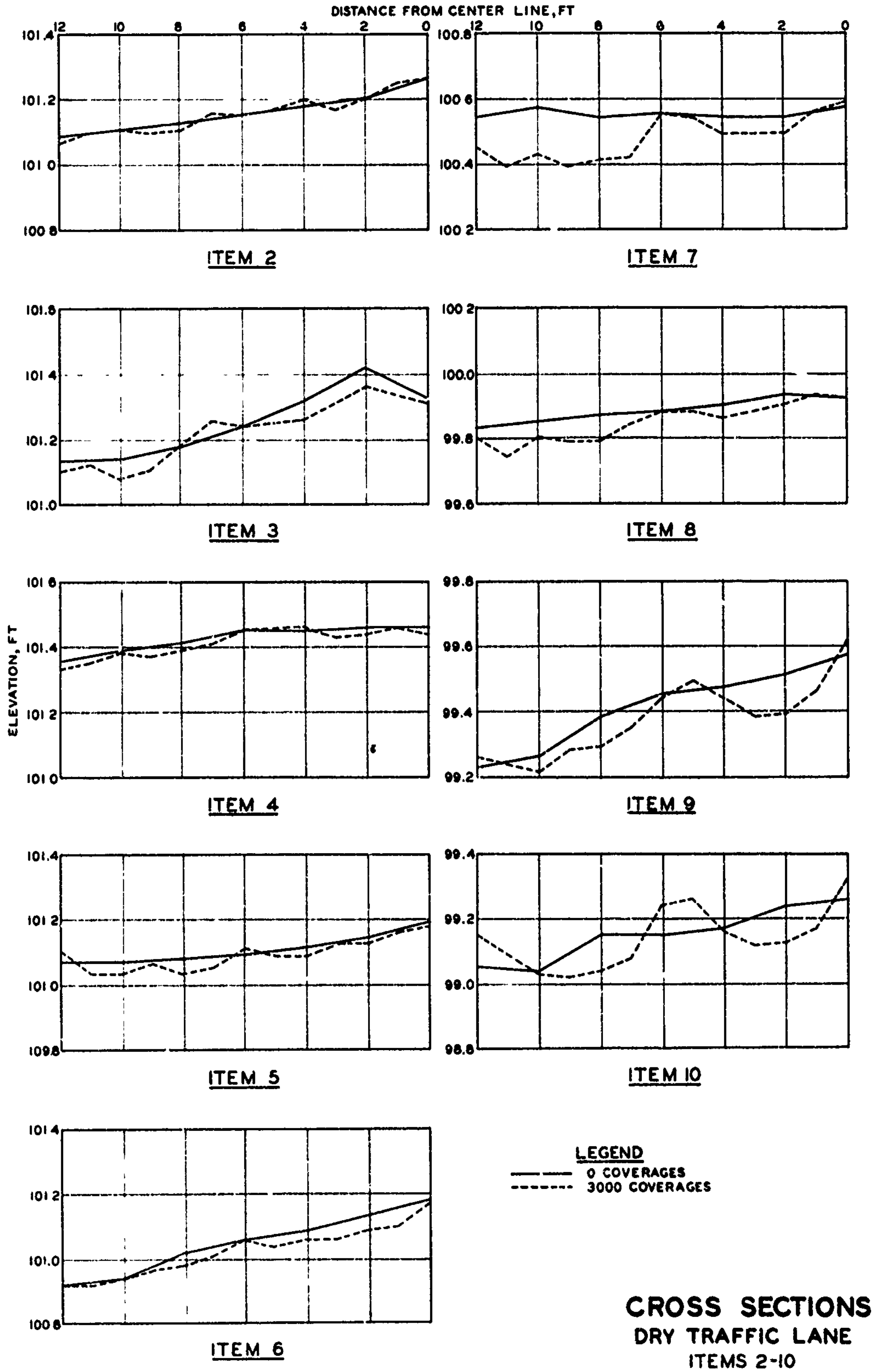
Photo 48. Test road from sta 10+50 to 9+00 during flood

Photo 49. View from sta 2+50 showing east loop during flood



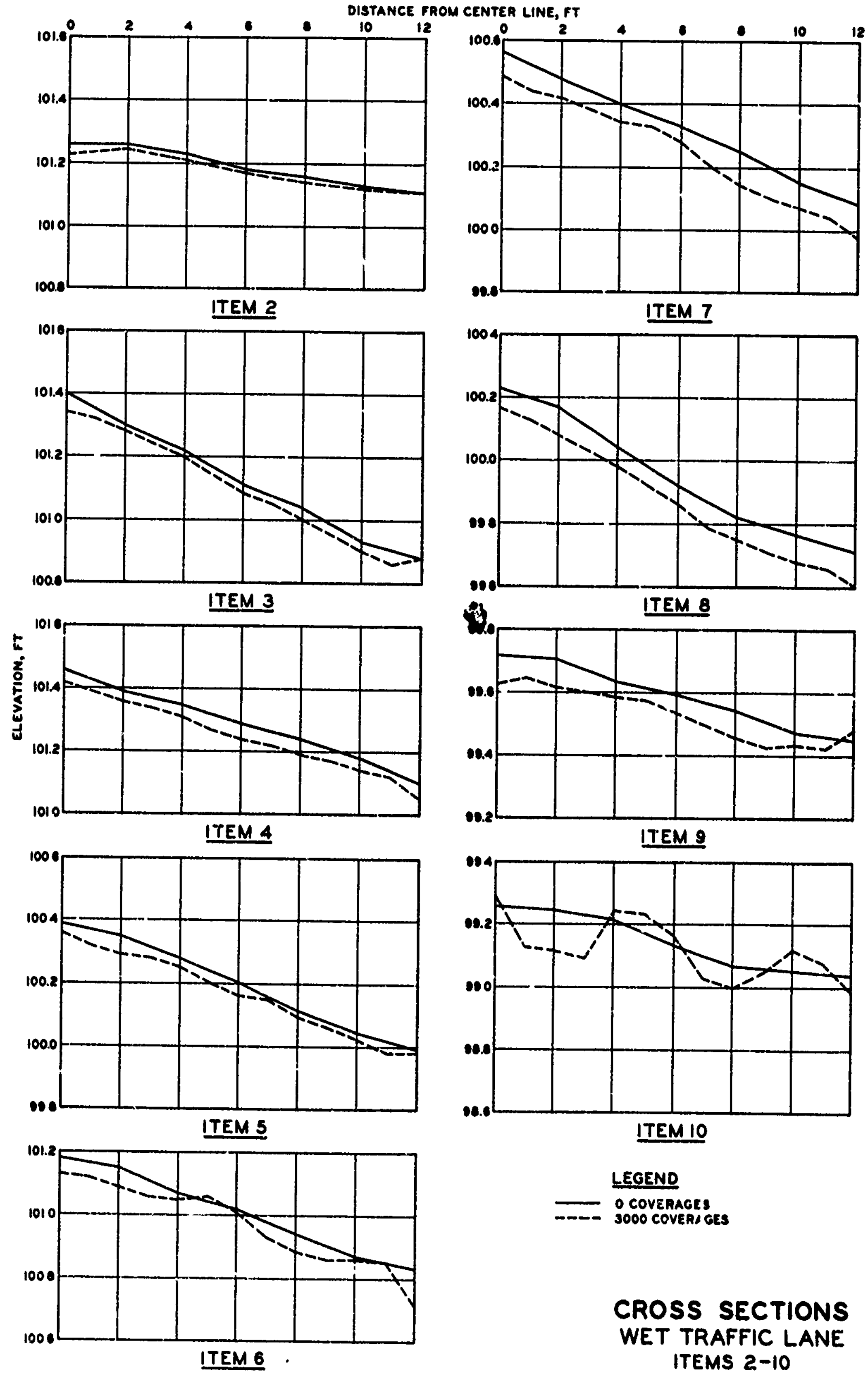
TEST ROAD LAYOUT

PLATE 1



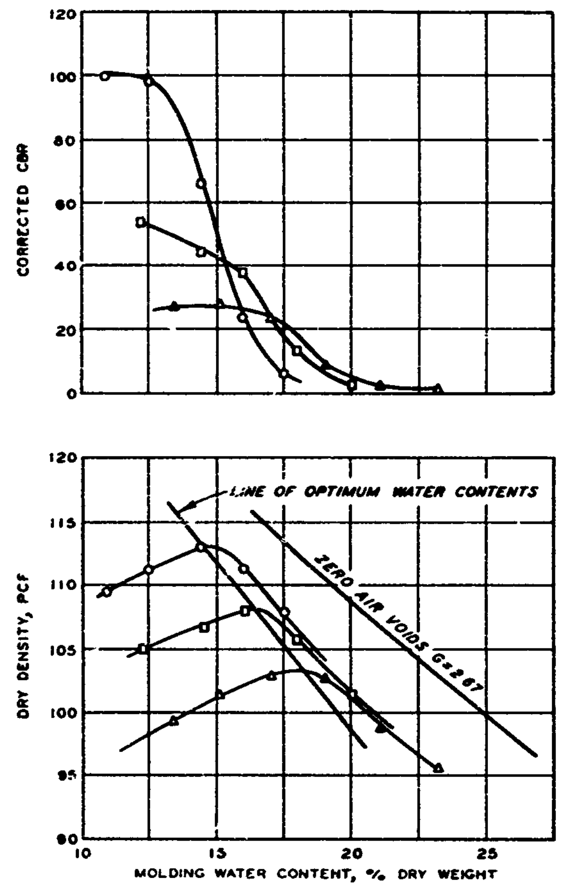
CROSS SECTIONS
DRY TRAFFIC LANE
ITEMS 2-10

PLATE 2

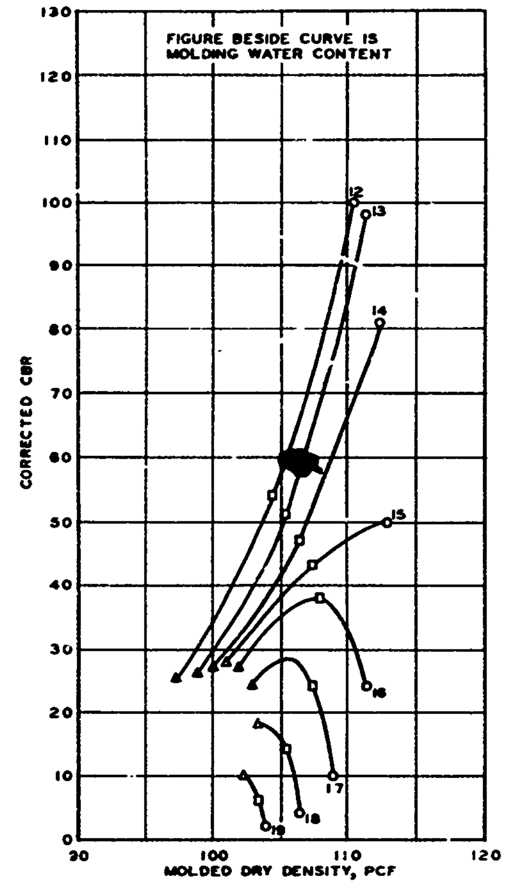


CROSS SECTIONS
WET TRAFFIC LANE
ITEMS 2–10

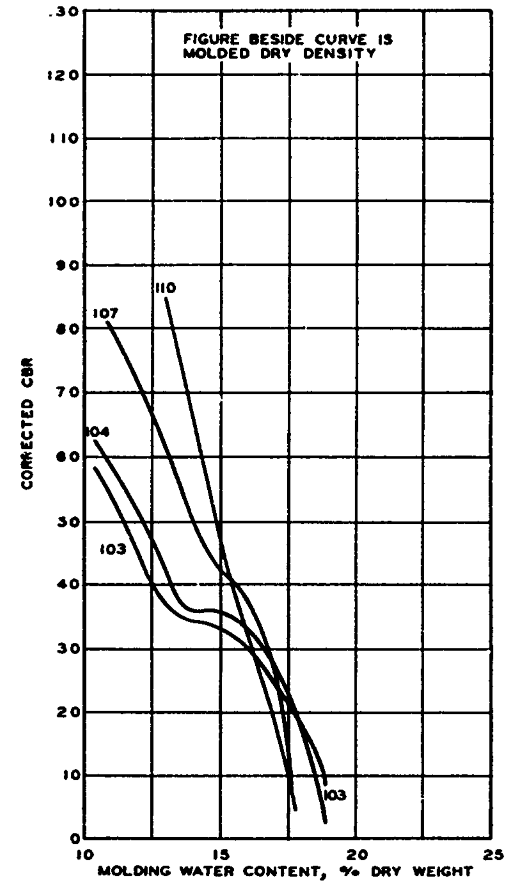
PLATE 3



MOLDING WATER CONTENT VS DENSITY AND CBR



MOLDED DRY DENSITY VS CBR



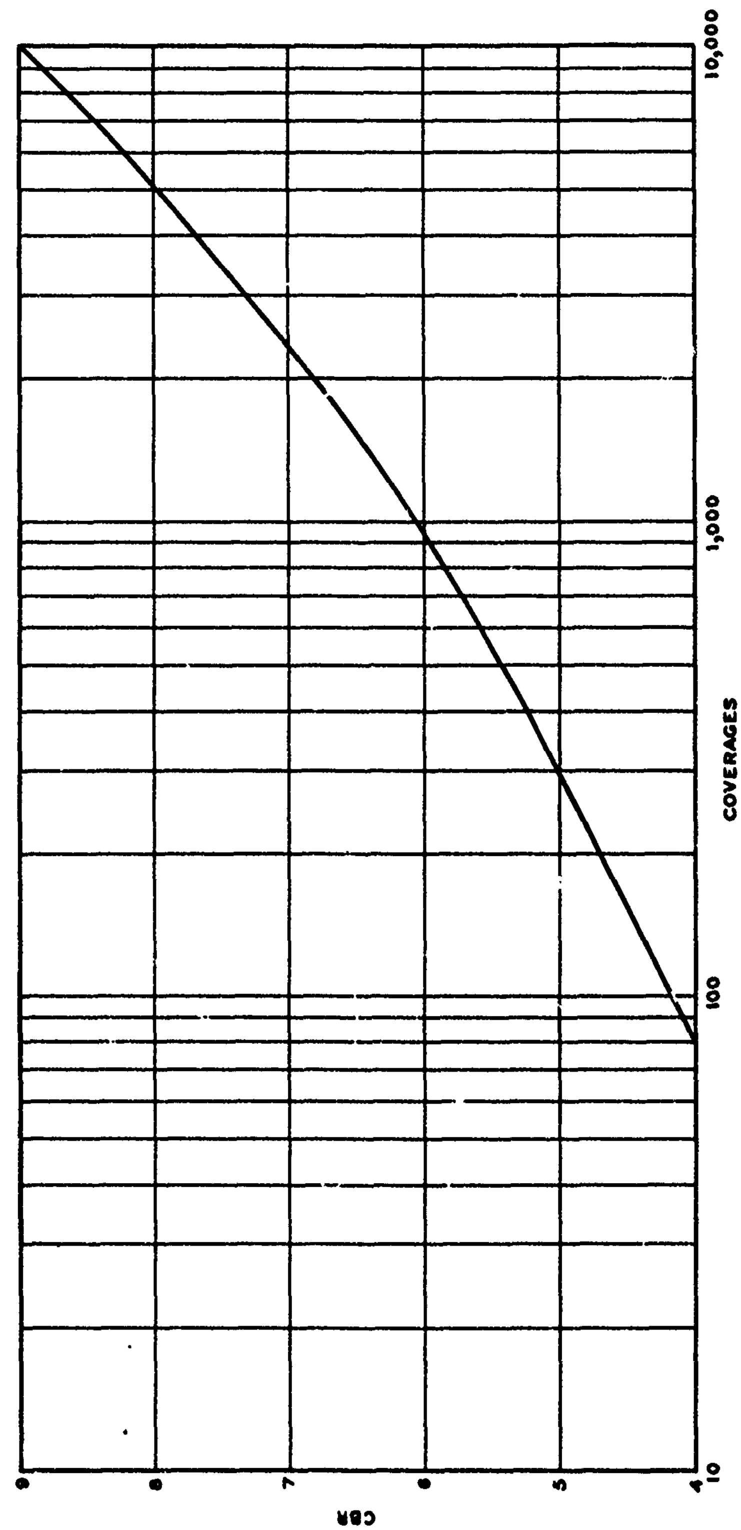
MOLDING WATER CONTENT VS CBR

LABORATORY COMPACTION:

	COMPACTION EFFORT	NUMBER OF BLOWS/LAYER
△	CE 12	12
□	CE 26	26
○	CE 55	55

CBR, DENSITY, AND WATER CONTENT DATA LEAN CLAY-AS MOLDED

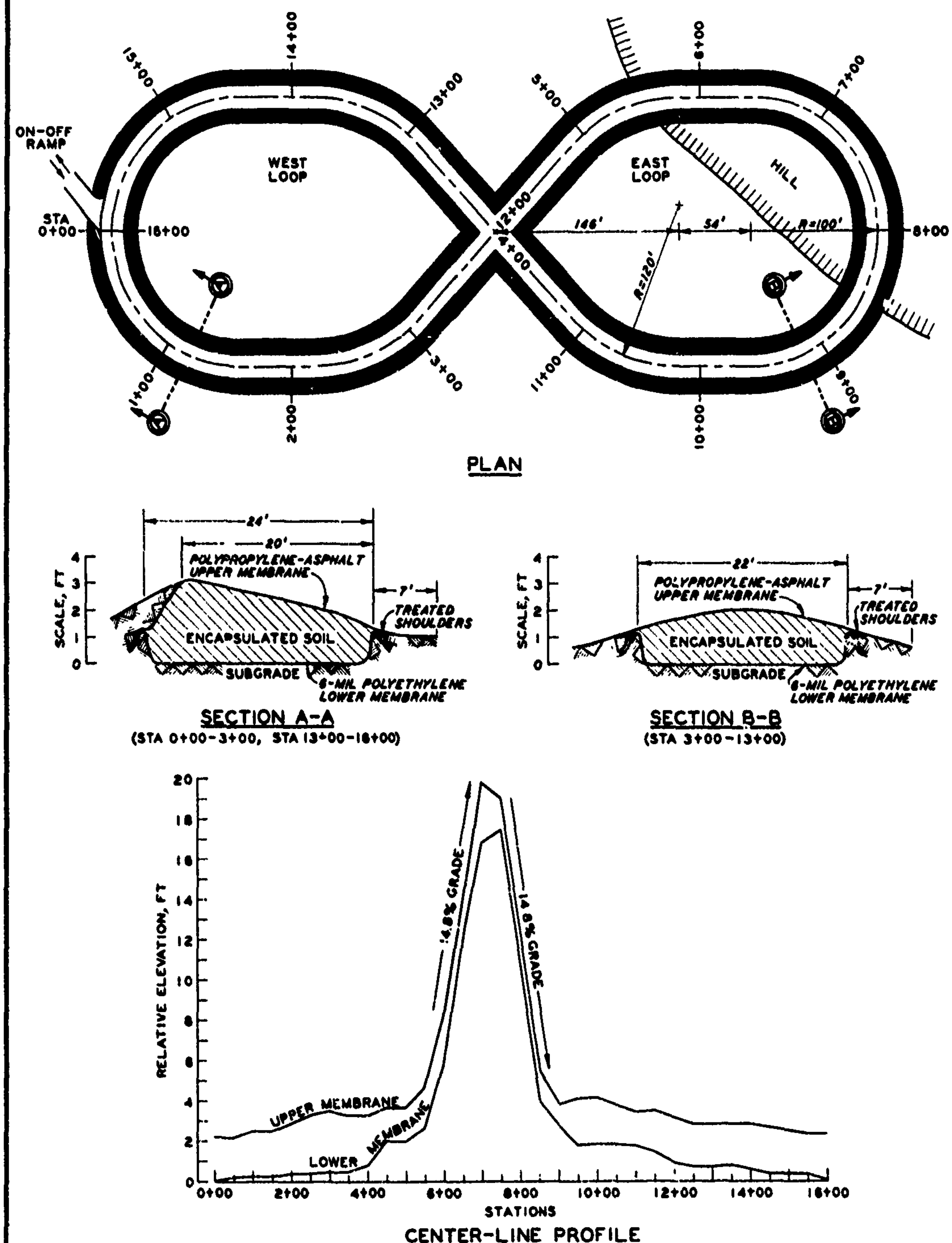
PLATE 4



NOTE: ONE PASS OF 5-TON, 6X6 MILITARY TRUCK EQUALS THREE COVERAGES OF 5000-LB SINGLE-WHEEL LOAD.

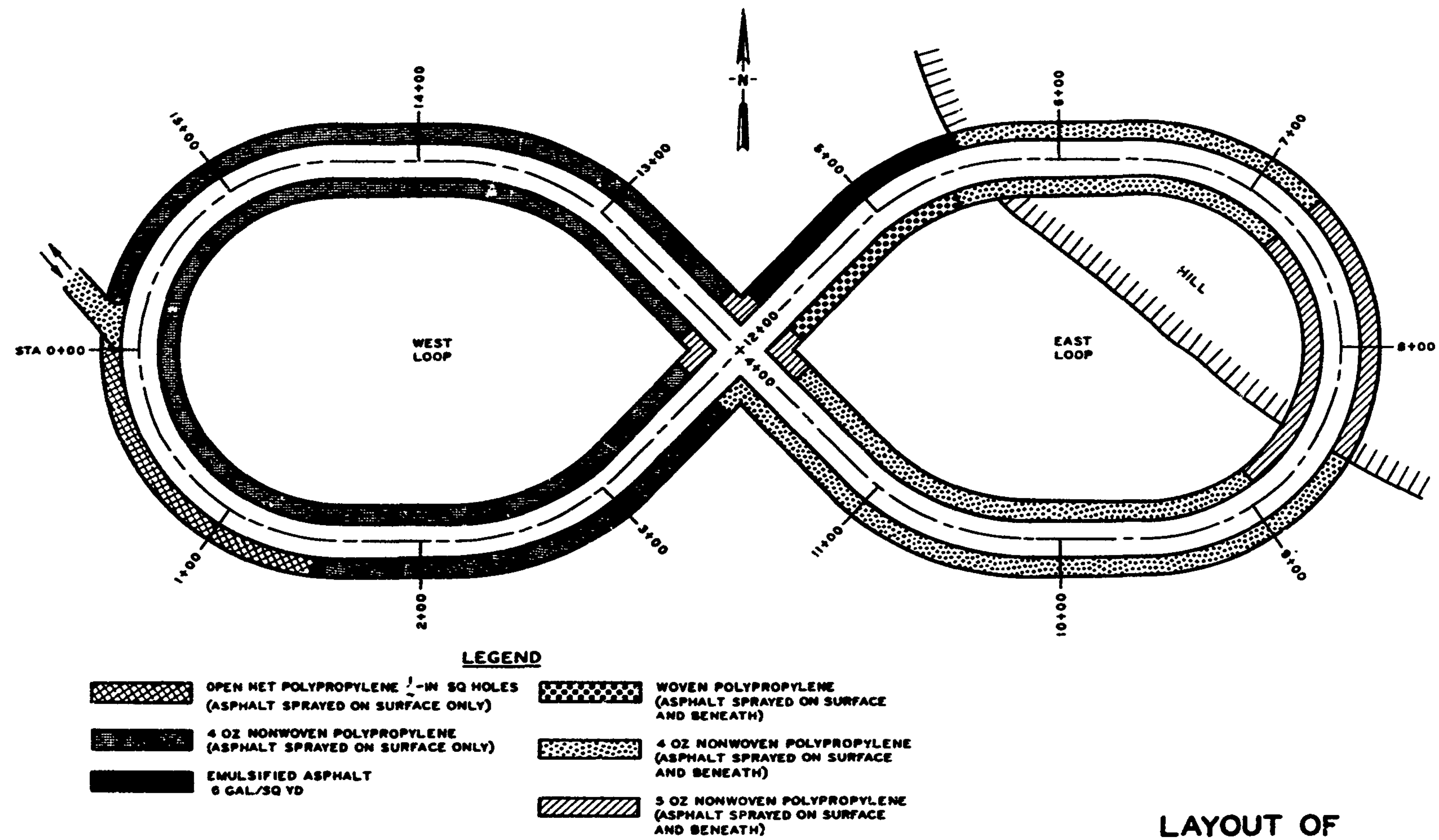
CBR DESIGN CURVE
5000-LB SINGLE-WHEEL LOAD
70-PSI INFLATION PRESSURE

PLATE 5

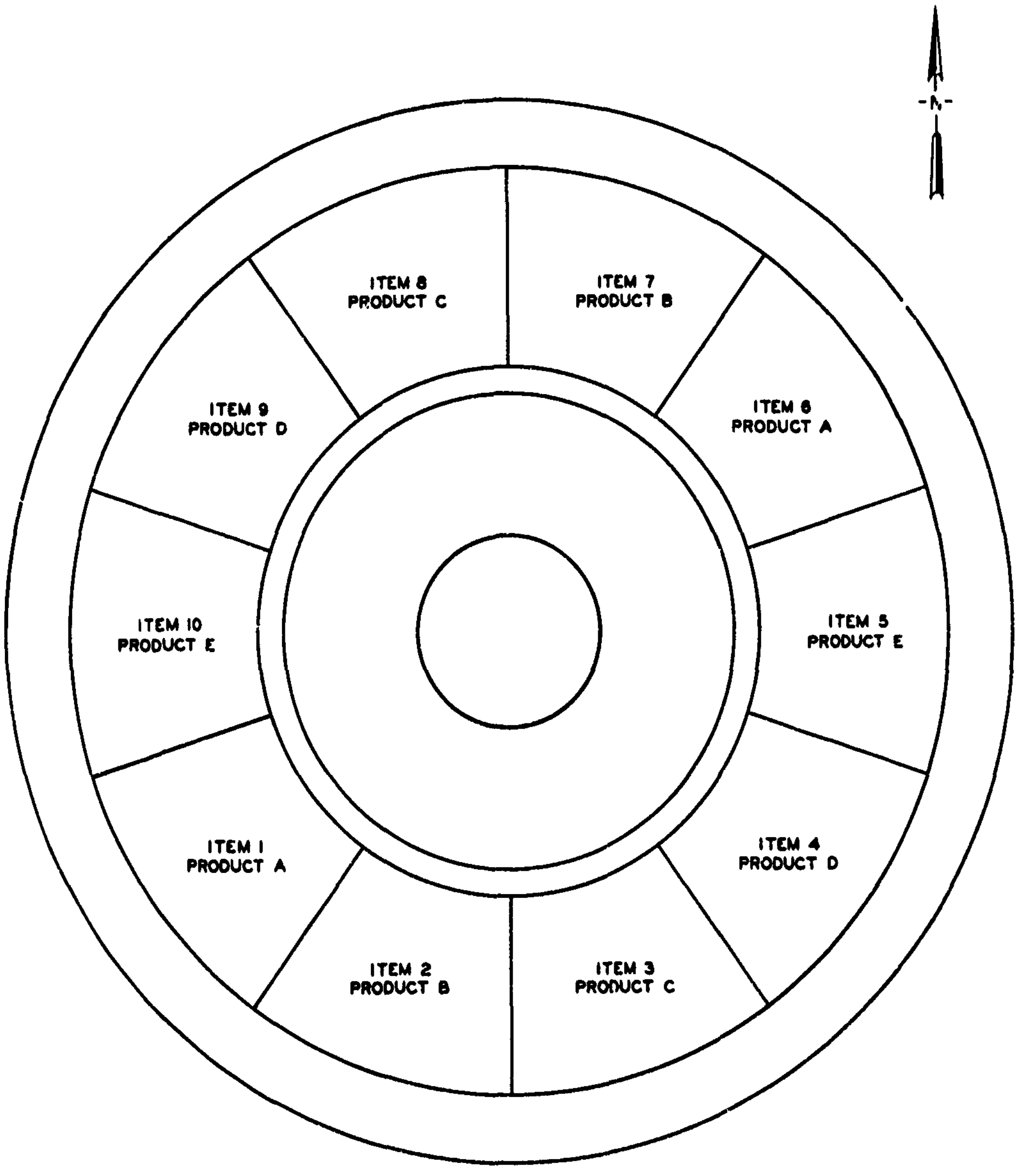


LAYOUT OF
DEMONSTRATION ROAD
PHASE III

PLATE 6



LAYOUT OF
SHOULDER TREATMENTS
DEMONSTRATION ROAD



LAYOUT
OF TEST ITEMS
PHASE IV

PLATE 8